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OIL SPILL MODEL SHELL: WORLDWIDE APPLICATION

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ABSTRACT

The ASA oil spill model has evolved to standard model software and input and output procedures. An embedded geographic information system (GIS) is used to organize, display and manipulate the data necessary as input to the model and supplementary data that aids in understanding and evaluating model predictions. This system is referred to as a model shell. Applications to new areas are performed by defining geographically specific data sets. Model shell application to such diverse areas as the Arabian Gulf, Ligurian Sea, Gulf of Mexico and Block Island Sound are presented to illustrate the concept. Examples of trajectory and fate model predictions in stochastic and receptor modes are given to show the versatility of the shell in addressing a full range of applications.

1. INTRODUCTION

The development and application of oil spill trajectory and fate models has historically been fairly active and because of the recent number of large spill events (e.g., *Exxon Valdez*, Arabian Gulf spill, Cyprus *Haven* spill, etc.) has received increased attention. A review of the state-of-the-art over the last decade (Stolzenbach et al., 1979; Davidson and Lawrence, 1982; Huang and Monastero, 1982; Spaulding, 1988; Reed et al; 1988) indicates that at any one time 30 to 50 models are available through a variety of government agencies, academic institutions and private consulting firms. Typically two to five algorithms are available to describe any one fate or transport process depending on the process. It is interesting to note that the survivorship of a given model is not particularly long due to the advances in understanding of spill behavior, the dynamic environment of the model hardware platforms and software, and the lack of continuing support by users.

The majority of models, according to the developers, can be readily applied to a variety of spill sites. In practice each model application is more accurately viewed as a single, independent application. The expense to apply the model to a new area is often substantial and additional code development, interfacing software, and environmental data sets are required. The trajectory and fate model software often change as well between separate applications and hence no standard is established with which to intercompare model predictions.

The present paper describes the development of an oil spill model shell suitable for worldwide use. The shell consists of the model software and user interface which remain the same for each application. The user provides data on shoreline location, winds, currents, and temperature for a particular study area. Additional geographically referenced data (e.g., shoretype, biological resources, socioeconomic resources, etc.) can be incorporated into the model as well through an embedded geographic information system (GIS). The user can rapidly switch from one area of interest to another by simply selecting the appropriate application. Applications can vary in geographic location or in resolution (detail) for a given geographic area.

Section 2 describes the oil spill trajectory and fate model shell. It also gives a summary description of algorithms used as well as an overview of the user interface. Forecast, stochastic, and receptor modes of model operation are then described. The procedures to set up the model for a particular application are presented in Section 3. To display the utility of the approach and provide a practical demonstration of its use, applications to two recent major spills: Mina Al Ahmadi (Section 4.1) and Cyprus *Haven* (Section 4.2), and to two spill drill cases: a spill drill scenario for Block Island Sound (Section 4.3) and a worst case scenario for a site near Morgan City, Louisiana in the Gulf of Mexico (Section 4.4) are presented. Use of the model in each of the three modes is illustrated in one of the four cases presented. Section 5 summarizes the advances of the present shell approach over existing spill models. Extensions of this approach to oil spill decision support model systems are also described.

2. OIL SPILL TRAJECTORY AND FATE MODEL

The Applied Science Associates, Inc. (ASA) oil spill model predicts the trajectory and fate of oil to include drift, spreading, evaporation, dispersion, emulsification, and shoreline stranding. The simulation allows for instantaneous or continuous spills with a constant release rate. Time-dependent releases are defined by the release of individual lots of oil or oil spillets. Each spillet is transported and weathered independently. The oil type, selected by the user from a library of oil types, is characterized by a distillation or boiling point curve.

Oil transport is calculated by the vector addition of the current field plus 3.6% of the instantaneous wind speed with an angle of 3° to the right of the wind. The drift factor and angle are based on Reed et al.'s (1990) recent comprehensive study comparing surface drifters with oil spill motion during a large (30 metric ton) experimental spill in the Norwegian Sea. Current data are provided by use of climatological data or a hydrodynamic model of the region. Wind data are specified by available weather forecasts or generated from historical data by a Monte Carlo procedure. In either case the wind is normally assumed spatially invariant.

Oil spreading is based on Fay's (1971) three regime formulation as modified by Mackay et al. (1980). Evaporative losses are described using Mackay and Matsugu's (1973) algorithm as revised by Payne et al. (1984). The oil is represented by a series of boiling point cuts (typically 8 to 15) which allows weathering based on the slick's age. The dispersion of oil into the water column is formulated by taking the product of the fraction of the sea surface subject to dispersion per unit of time times the fraction of the oil not returning to the surface slick (Mackay et al., 1980). A mousse formation or emulsification algorithm, based on Mackay et al. (1980, 1982), is employed to predict the increase in water content of the oil. Mooney's (1951) equation is then employed to determine the viscosity of the oil in the slick, which is subsequently modified to account for evaporative effects. Oil-shoreline interaction is based on a simplification of the COZOIL model (Reed et al., 1989). Oil retained on the shoreline is a function of shore type. Subsurface transport is not implemented in the present version of the model shell.

The spill model and the related input/output interface software are designed as a shell. Application to a specific area is made by specifying the appropriate geographical region and the related environmental data base (e.g. winds, currents, shoreline location/type, etc.). The model also has an embedded Geographic Information System (GIS) that allows infrastructure, biological resources, socioeconomic features and other data to be manipulated and displayed.

The hardware/software system is designed to assure that the model is extremely user-friendly, operates quickly and effectively in an on-line, stand-alone, response mode and uses clear, concise graphical procedures to enter data and display model output. The model is configured for operation on an MS/DOS, IBM/COMPAQ or compatible computer with a math co-processor, a 60 MB ESDI disk drive, and 1 MB RAM. Input/Output is via a VGA color monitor. HP Paintjet or Laserjet printers can be used for printed output. A Microsoft mouse and the monitor keyboard are employed to control the program input, execution, and output. The model software is programmed in Microsoft C and Fortran. The model is controlled and options selected using pull-down menus and point-and-click techniques with the mouse.

The first level menu contains the selections: LOCATION, DATA, RUN MODEL, REPORTS, SYSTEM and QUIT. LOCATION allows the user to select the geographic area of interest. DATA allows two options: VIEW and ENTER. In VIEW the user can look at the existing data sets used as input to the model. Data sets include shore type, wind time series and currents. ENTER allows the user to create or update environmental data (e.g. wind) and geographically referenced data. Hydrodynamic and shore type data cannot be changed by the user from within the shell. The system allows limited GIS capabilities which are designed toward the quick entry and display of background information relevant to spill response decision making or contingency planning. Ten types of generic data are user-definable, with color coding and separate icons to discriminate between various classes of data. Each resource (point, line, or polygon) may have a variety of information attached to its geographic position. Typically the GIS is used to display biological resource information, major spill response equipment, oil refineries and wells, and spill distribution data from overflights and ship observations. This may also include the same area at different spatial resolutions. RUN MODEL has three modes of operation as described below.

Trajectory and fate forecast/hindcast mode

In this mode the model predicts the trajectory and fate of oil for a specified spill scenario (release location; oil discharge rate, duration, and type; start date). The environmental data (e.g. currents and winds) are user specified or included in the model data base. This information may come from climatological, historical, or forecast data and can be derived either from observations or model predictions. An option is also available to allow the user to relocate spillets based on observations and continue the simulation. The model predicts a specific trajectory and fate for each spill. The output shows the oil distribution and mass balance versus time. This mode is typically used for spill response, spill drills, or hindcasts of spill events.

Stochastic Mode

Stochastic mode simulations determine the most probable trajectory envelopes and coastal areas at risk in the event of a spill(s) from a particular location(s). For these simulations the environmental data (e.g., winds) are selected from a statistically based time series to replicate the range of conditions expected for the particular season or month of interest. Repeated simulations are performed, randomly sampling the environmental time series (e.g., wind) start time.

Model predictions are summarized in terms of probability contours of oil impacting given water areas or shorelines. If resource information (biological, socio-economic) is included in the data base, "hits" on resources can also be determined.

These simulations are primarily used in spill contingency planning and risk analysis and allow the user to rapidly assess resources at risk and identify probable locations for spill cleanup equipment.

Receptor Mode

In this approach statistical simulations are performed as in the stochastic mode but the calculations are run backwards in time. The starting location for the simulation is a particular area or resource of concern. The results of such simulations are presented in terms of probability contours that give the likelihood that spills released from a variety of sites will impact a particular resource of concern. Contours of the minimum time for the spill to travel from a potential spill site to the area or resource of concern are also presented.

This type of simulation is used to identify probable spill sources given the current location of the oil or to identify the spill areas from which a particular resource is vulnerable. As an example this calculation could quickly identify the principal avenues from which a spill is likely to reach a desalination or power plant intake site.

REPORTS presents a summary of spill predictions of trajectory motion and mass balance versus time in either graphical or tabular form. This data can be output to a printer for archiving or dissemination. SYSTEM provides access to several general features. It contains a HELP facility for the main menu (specific HELP facilities are also available in each sub-option), a FILE MAINTENANCE procedure to delete unwanted wind and oil spill simulation files, and options to specify the display units (kilometers or nautical miles) and type of printer to which output will be sent.

3. OIL SPILL MODEL SETUP AND IMPLEMENTATION STRATEGY

The procedure used to set up the model for a new application is highly dependent on the time available to accomplish the task. Summarized below are the strategies employed for the quick response and typical (e.g., contingency planning, spill hindcast, natural resource damage assessment, etc.) set up procedures.

RAPID RESPONSE

The key focus here is to provide accurate, first order spill trajectory and fate calculations within 6 hours of notification of the spill for any place in the world. Given the dynamic evolution of spills shortly after their initial release and the need to make rapid decisions on deploying cleanup equipment, it is critical that predictions be produced quickly.

In this initial application the strategy is to obtain data from existing digital data bases to the maximum extent practical. In most cases these data sets are available from federal or state governments. Interface software allows one to rapidly extract the data and prepare it for input to the model shell. The principal data sources employed for the primary data are summarized below.

Shoreline location

Shoreline information is obtained from the CIA-World Data Bank II (Gorney, 1977). The data were digitized from existing maps with scales ranging from 1:1 to 1:4 million. The data set is divided into five regions: North America, South America, Europe, Africa and Asia. The data also include rivers and international boundaries. The nominal resolution is approximately 0.5 km. The data set is sub-sampled if large domains are covered.

Wind

Wind information, in the form of probability distributions by direction and speed is available from airports, weather stations and offshore buoy observations around the world. These data (International Station Meteorological Climate Summary), stored on CD-ROM, are available from the Federal Climate Complex, Asheville, North Carolina. A menu driven, window based geographical selection procedure is used to determine the data availability and to rapidly access the information.

These probability distributions are then used to generate wind time series for the period of interest. This distribution data unfortunately only allows one to produce a simple zeroth order Monte Carlo times series (e.g., no temporal correlation).

Currents

For medium term simulations (5-30 days) the principal currents of concern are the long term mean surface currents. For world wide application the most consistent and readily available data are the U.S. Navy Marine Atlas series. The atlas provides seasonal, broad scale resolution of coastal current features.

The model shell employs two separate grids to store shoreline and current data. The shoreline grid is typically four times the resolution and nested within the hydrodynamic model grid. The overall grid domain is restricted to 100 by 100 for computational storage and speed considerations. The resolution of the area under study is user selectable.

With the three data sets described above, first order calculations are made. As the spill situation evolves, more accurate data can be prepared and developed. This normally takes the form of a separate application. Typical improvements make use of: NOAA/NOS or Defense Mapping Agency (DMA) charts for the shorelines and local weather forecasts or observations for the wind field.

Observations on the location of the oil can be used to re-initialize the simulation and make revised forecasts. These revised forecasts may be made for the slick in its entirety or selected portions of the slick that pose a particular threat to an important resource.

As time allows, critical geographically based information is normally added. Data of particular interest include: biological resources, socioeconomic features, spill response equipment and status, oil facilities, and personnel deployments, among others.

The level of sophistication in model application and the accuracy and quality of the data are determined by the user's needs, resources and available time.

TYPICAL OPERATION

For the typical application (e.g., contingency planning, spill hindcast, natural resource damage assessments, etc.) application the user has the benefit of selecting appropriate data sets to meet operational and accuracy requirements for the intended use. This application is scheduled and the user can devote the necessary time to achieve the desired level of accuracy. The basic data elements remain the same as for the rapid response.

4. MODEL APPLICATION TO SELECTED SPILL SITES AND SCENARIOS

Application of the shell model to a wide variety of spill cases is described in the following sections. Examples are chosen to show the worldwide capability of the approach and to illustrate the model's use for spill response, spill contingency planning and resource vulnerability assessment.

4.1 Mina Al Ahmadi Spill

Application of the shell model to this spill is described in detail by Spaulding et al. (1991), only a brief summary is presented here.

Iraqi soldiers in Kuwait deliberately released oil into the Arabian Gulf from five tankers moored near the Mina Al Ahmadi terminal and from discharge lines to the offshore Sea Island terminal. The exact size of the spill is unknown but the estimates range from 700,000 to 11 million barrels (OPB, 1991). The Defense Department reported that the spill began on about January 19, 1991 and was effectively stopped on January 26, 1991 when U.S. aircraft destroyed the manifolds that control the oil flow from the onshore storage tanks to the terminal. A second and much smaller spill was reported by the Saudi Arabian Meteorological and Environmental Protection Administration (MEPA) as a result of an Iraqi attack on an oil refinery and storage facility at Ras Al-Khafji near the Saudi-Kuwait border on January 24, 1991. A third spill from the Mina Al Bakr terminal was also started by the Iraqis in late January. The actual spill rate was unknown but roughly estimated to be in the thousands of barrels per day.

The exact movement and weathering of the spill is difficult to determine since remote sensing observations and aerial mapping data either were not collected or were not available because of military restrictions on the dissemination of information. A picture of the major movements of the spill can however be assembled from shore based sightings and the limited remote sensing data available. Table 1 summarizes the approximate dimensions, location and state of the oil versus time since the release. No attempt is made to distinguish between the Mina Al Ahmadi and Ras Al-Khafji spills as the data base is too weak to make such an assessment.

The spill traveled toward the southeast roughly paralleling the coast, influenced primarily by the predominantly northwesterly winds. The spill extended from the shore to 50 or 60 km offshore. The mean spill transport rate was approximately 7-12 km/day depending on the wind conditions. Extensive oiling of the coast was observed.

Figure 1 shows observations of the surface oil based on an analysis of aerial overflight data for January 27, 1991 and February 18, 1991. The January 27, 1991 sketch is from the Pentagon press briefing that day by General Schwarzkopf. The February 18, 1991 information was obtained from the International Interagency Oil Spill Assessment Team.

Field reports and sightings of the spill indicated that the oil weathered rapidly. By mid to late January the oil was in thick patches and sheen and numerous tar balls were observed. By late February 1991 oil weathering was continuing with extensive areas of sheen and a few small patches.

The oil spill model was applied in a response mode to forecast the spill motion using hydrodynamic data based on simulations of the tide, wind and density forced flows (Spaulding et al., 1991). Winds were based on forecast conditions for Das Island in United Arab Emirates waters in the lower Gulf. It was impossible to obtain wind data or forecasts for the upper Gulf because of military restrictions on the release of the data. When forecast winds were not available statistically generated winds, based on the wind speed-direction probability distributions at Das Island (IMCOS, 1981), were used. Forecasts were repeated every few days. The model predicted trajectory showed the oil moving parallel to the coast toward the southeast. The predicted oil location was within 5 km of the observed position on January 27, 1991. The model predicted the oil to arrive at Abu Ali Island about February 8-10, 1991. Oil was first observed at Abu Ali Island on February 15, 1991. The model hence overpredicted the transport rate by about 20% over the month since the release. The model indicated that the oil would remain trapped for a considerable time northwest of Abu Ali Island. Oil transport southeast of Abu Ali Island was predicted to be critically dependent on westerly winds, in agreement with observations. The major part of the oil slick remained effectively trapped northwest of Abu Ali Island.

The model simulations were rerun after the spill event using a combination of observed and forecast winds for the upper Gulf, provided by the International Interagency Response Assessment Team. The circulation data were obtained from the hydrodynamic model. Figure 2 shows the model predictions compared to observations on February 18, 1991. The model reasonably predicts the spill behavior and the size of the spill. The model predicted spill mass balance shows rapid evaporative loss of 35% of the spill volume within the first three days after the initial release. This estimate agrees with those given by Saudi MEPA officials.

Application of the model in the stochastic mode for contingency planning purposes is shown in Figure 3. The figure depicts the probability of the sea surface and shoreline being impacted if a spill should occur at a site 10 km east of Jubayl, Saudi Arabia in the Arabian Gulf. Jubayl is the location of a major industrial complex and desalination and power plant facilities. The model predicts the principal area of oil impacts to be southeast of the release site, approximately paralleling the coast and extending to Bahrain.

Results of a receptor mode calculation for the industrial complex at Jubayl are shown in Figure 4. Figure 4a shows the probability of oiling of the water surface area and 4b the minimum number of days for the oil to be transported to the facility. One, three, five and ten day intervals are shown to reflect various stages of oil weathering. The grid resolution is approximately of 11 km. The model clearly indicates that the principal avenue of exposure for this facility is from spills which occur to the northwest.

4.2 Cyprus Haven Tanker Spill

The Cypriot registered tanker *Haven* carrying 1,000,000 barrels of extremely viscous Iranian crude oil caught fire and began burning about 8 km south of Arenzano, Italy (to the west of Genoa in the Ligurian Sea) on April 11, 1991 at 1:00 A.M. local time. The fire was caused by a midship explosion during an oil transfer operation. According to Genoa port authorities the fire consumed the majority of the lost oil, roughly estimated to be 300,000 barrels. The burning tanker was towed to within 2.5 km offshore of Arenzano and sank in 70 m of water on April 14, 1991. The tanker currently rests on the sea floor with small amounts (~7200 gallons per day) of thick, viscous oil being released from the vessel (OSIR, 1991a).

The amount of oil released to the sea during the period from the initial explosion to the sinking is unknown. The majority of the lost crude appears to have burned however shoreline surveys (OSIR, 1991a) indicate considerable oil did indeed escape the fire. The most recent (May 1991) estimate by experts suggest a spill of approximately 310,000 barrels (OSIR, 1991b).

The mean currents in the area are to the southwest paralleling the shore while the winds are generally from the north. The combination of these environmental factors transported the spilled oil toward the southwest. By April 15, 1991 oil was observed along a 30 km stretch of coastline to the west of Arenzano. Traces of oil extended as far southwest as the Italian city of Imperia, 55 km from the French border. Oil washed up on the French Riviera on April 24, 1991 near Nice, France (OSIR, 1991a). It was estimated that 40 km of Italian shoreline were oiled (~1500 barrels) extending from Genoa to Menton, Italy.

ASA was notified of the accident at 15:00 EST on April 12, 1991. The spill model was set up for the general region of the Ligurian Sea extending from 2.95° to 11.14° E and from 41.39° N to the coastline. Shoreline location data were obtained from the CIA world data bank (Gorney, 1977). Bathymetric data were specified using NOAA/NODC SYNBAPS data. Wind data were statistically generated based on the direction-speed frequency distribution data. The distribution tables were extracted from the NOAA International Station Meteorological Climate Summary Station No. 161200 (WEO) at Genoa (44.42°N; 8.85°E) The direction-speed distribution diagram was based on an analysis of historical data at the site from 1973-1989.

The currents in the area were initially specified as uniform, shore parallel (to the southwest) at 35 cm/sec based on the estimated residual surface summer current patterns (Lacombe and Tchernia, 1971; Miller, 1983). Tidal currents were ignored since they are generally quite weak throughout the Mediterranean (Miller, 1983; Defant, 1961).

The spill start date was set at April 11, 1991, 0100 (local time) and the oil was released at 44.26° N latitude and 8.69° E longitude. An instantaneous release of 100,000 barrels of heavy crude was arbitrarily assumed. The model predict that the surface oil traveled a distance of 70 km over three days with an average transport rate of 23 km/day. The model indicated that the oil would impact the coast about 50 km southwest of the spill site.

A series of sensitivity studies was performed to assess the impact of alternate descriptions of the currents (speed, direction) and wind (based on different stations) on the predicted trajectory of the oil. The sensitivity study indicated the predicted mean paths were consistent for the cases studied, however the transport rates could vary substantially (~ 50%) depending on the exact current conditions.

The simulation results were provided to representatives in Italy and numerous press and television news media by 19:30 EST on April 12, 1991. The time from initialization of the modeling effort to delivery of the first set of trajectory predictions was 4 1/2 hours. This application represents a rigorous test of the utility of the shell to allow rapid setup and accurate predictions.

During the next two days a hydrodynamic model was applied to the area to predict the residual surface current pattern, and simulations of the spill rerun. The hydrodynamic model predicted circulation was consistent with general patterns noted in Miller (1983) showing shore parallel southwesterly flows of 30 cm/sec in the spill path.

Figure 5 shows the model predicted spill path from both the original spill site assuming a release on April 11, 1991 as well as the site of the sinking with a release on April 14, 1991. Hydrodynamic data were provided by the model described above. The winds were statistically generated as for the earlier simulation.

The model predicted spill motion is consistent with the spill observations (OSIR, 1991): shore parallel transport to the southwest. The model predicted the oil to reach the shore within 7 km from the spill site, which was very close to the observed standing locations.

4.3 Block Island Sound Spill Drill

The U.S. Coast Guard (USCG) requested ASA's assistance in developing a spill scenario for an On Scene Coordinator (OSC), Regional Response Team (RRT) Pollution Response Training Exercise held on April 25, 1991 at the US Coast Guard Academy.

The spill scenario was as follows: At 3:00 a.m. on April 25, 1991, the 660 foot tankship *Omi Leader*, loaded with 35,000 long tons of No. 6 black oil, was transitting Block Island Sound inbound for the Wyatt Oil Terminal in New Haven, Connecticut. The *Omi Leader* was approximately 4 miles south of Misquamicut Beach, Rhode Island, when a port to port collision with the outbound 580 foot bulk chemical tankship *Stolt Sapphire* occurred. The *Stolt Sapphire* was two-thirds loaded with various bulk chemicals.

The force of the collision caused severe damage to the *Stolt Sapphire's* port bow area and to the port wing tanks, and ignited the isopropyl alcohol loaded in the port wing tank. All port wing tanks on the *Omi Leader* were ruptured. Heavy No. 6 black oil immediately began to flow out of three of the five wing tanks. Two of the port wing tanks were used for ballast.

As the ships slid port to port, the momentum of the vessels slowed and they separated. The pilot on board the *Omi Leader* communicated, via radio, with the *Stolt Sapphire* to assure the safety of the crew. No injuries were reported. Remote fire fighting efforts were immediately initiated aboard the *Stolt Sapphire*. Both ships notified Coast Guard Station New London of the the collision with resulting fire and oil discharge. Coast Guard assistance was requested.

The ships maintained their positions and conducted damage control. By 6:00 a.m., the fire onboard the *Stolt Sapphire* was extinguished, and both vessels anchored. The *Omi Leader* anchored in position 41°15.7' N, 71°50.0' W and the *Stolt Sapphire* anchored in position 41°17.0' N, 71°48.0' W. Both ships continued to leak cargo from their damaged tanks while onboard efforts to control the spillage continued.

The spill lasted three days discharging 12,000 barrels per day of No. 6 oil at 41.26° N and 71.83° W. The winds were assumed to be 3-5 m/sec from the south-southeast during the spill period. Currents in the area are dominated by the semi-diurnal with tide peak magnitudes of 50 cm/sec in the alongshore direction.

The model was set up for the area using the NOAA/NOS shoreline data set. The model domain extended from 70.9° W to 73.9° W and from approximately 40.7° N to the shoreline. Tidal currents in the area were defined using the University of Rhode Island, Ocean Engineering hydrodynamic model predictions (URI, 1984) with a 2.5 km grid system. Residual currents in the area are quite small and were ignored.

Model predicted surface oil distribution 3 days after the spill are shown in Figure 6. The predictions show extensive oiling of the western Rhode Island and eastern Connecticut shoreline. Shoreline impacts are predicted as far west as the eastern tip of Long Island.

The transport of oil is primarily determined by the relative roles of the north/northwesterly movement due to the wind and the east-west advection by the ebb-flood tidal current patterns. The enhanced dispersion of the oil through the Race (passageway connecting Long Island to Block Island Sounds) is caused by the strong (e.g., 2-2.5 m/sec) tidal currents in the area (URI, 1984).

4.4 Gulf of Mexico-Louisiana Coast Spill Scenario

As part of an oilspill response exercise the model was applied to predict the fate of oil from a worst-case spill scenario for a site near Morgan City, Louisiana. The spill scenario was developed by the U.S. Coast Guard and presented in the National Status Contingency Plan report (Skinner and Reilly, 1990). The worst-case scenario involves a crude oil producing platform located off the coast of Louisiana and a 218,447 gross ton supertanker (the *Exxon Valdez*, was 110,831 gross tons) enroute to off-load its cargo of Basrah crude oil at the Louisiana Offshore Oil Platform (LOOP)--both the platform and the supertanker are common in this zone. In this scenario, the tanker suffers a loss of power and steering and collides with the oil production platform. Both the vessel and the platform sustain significant structural damage, with two of the ship's forward cargo tanks holing and the platform receiving damage to the well head and blowout preventers. As a result of the collision, fire erupts on the platform and the tanker. Due to the loss of power on the ship, the crew is unable to fight the fire with the ship's main fire pump; the fire also blocks access to the ship's emergency fire pump located near the ship's forepeak. The fire rages out of control for twenty-four hours and causes structural weakening of the ship. The structural weakening in turn allows the vessel to break apart and sink, releasing 85 percent of its crude oil cargo of 1.2 million barrels.

The heavy crude oil carried has poor dispersion characteristics which, coupled with the relatively low daily sea and air temperatures during the early February spill scenario means that evaporation will be lower than normal. Containment of the spill in over 0.6 m seas would be difficult.

The spill model covers the entire Gulf of Mexico from 80.2° to 98.3°W and from 23.4° to 30.8°N. The shoreline data is obtained from CIA World Data Bank (Gorney, 1977).

The spill site is located at 28.9°N and 90.03°W and instantaneously releases 1.2 million barrels of Basrah crude oil on February 14. The winds are constant at 15 m/sec from the southeast. Mean surface currents on the shelf are assumed minimal to minimize the probable time for shoreline response.

Figure 7 shows the oil spill model predicted oil distribution three days after the release. The oil is transported to the northwest in response to the southeasterly winds. Oil initially reaches the coast within 15 hrs after the release. Oil impacts the coast over about 50 km and the last of the oil arrives at the shoreline 80 hrs after the spill starts. The oil mass balance at the end of day three shows that 10% is on the water surface, 20% is evaporated, and 65% is on the shoreline. The remaining oil is dispersed in the water column.

5. CONCLUSION

The oil spill shell model system, which operates in forecast/hindcast, stochastic, and receptor modes allows the user the potential to rapidly and accurately forecast spill trajectory and fate for any region of the world. Illustrative examples of model application to the Arabian Gulf, Ligurian Sea, Block Island Sound and the Gulf of Mexico have clearly demonstrated the model's responsiveness and capabilities. Exceptionally rapid response times are readily achieved with the shell approach given worldwide digital data bases for shoreline location, wind, and mean surface current. As an example, the Genoa spill simulations were completed within 4 1/2 hours after notification of the spill event.

The shell model is easily portable from one geographic area to another. It can also be configured for a variety of spatial resolutions for a given geographic area. The use of standardized procedures for the fate algorithms makes it possible for the user to directly compare and contrast results between two applications. The user interface is designed for ease of use and takes extensive advantage of graphical procedures to input and output data.

The basic shell concept has proven to be an extremely powerful one and has gained enthusiastic support from a wide range of users. The oil spill shell modeling framework is therefore being extended to include an oil spill tactical and response model and an impact assessment model. A prototype of this integrated oil spill response decision support model system has been developed and applied to Prince William Sound (Anderson et al., 1990). Application of the basic shell strategy to natural resource damage assessments for oil and hazardous chemical spills is currently in progress.

Acknowledgements

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Table 1 Sightings of oil from the Mina Al Ahmadi and Ras Al-Khafji spills.

Date	Spill Location/Orientation	Spill Dimensions	Reference
Jan 19, 1991	Spill release begins at Mina Al Ahmadi		
Jan 23, 1991	Start at Mina Al Ahmadi terminal, southeast along Kuwait coast	10 miles long 2 miles wide	Pentagon Press Briefing, Pete Williams
Jan 27, 1991	Oriented northwest-southeast along Kuwait-Saudi coast	see Figure 24	Pentagon Press General Schwartzkopf
Feb 1, 1991	Oriented northwest southeast along Kuwait Saudi Arab coast leading edge 50 miles north of Al-Jubayl	125 miles long 30 miles wind	Pentagon Press Briefing
Feb 14, 1991	Leading edge of slick reaches Abu Ali		T. Hawley, OPB
Feb 18, 1991	Leading edge rounding Abu Ali trailing edge at Ras al Saffaniya	see Figure 24	W.Lehr, NOAA overflight

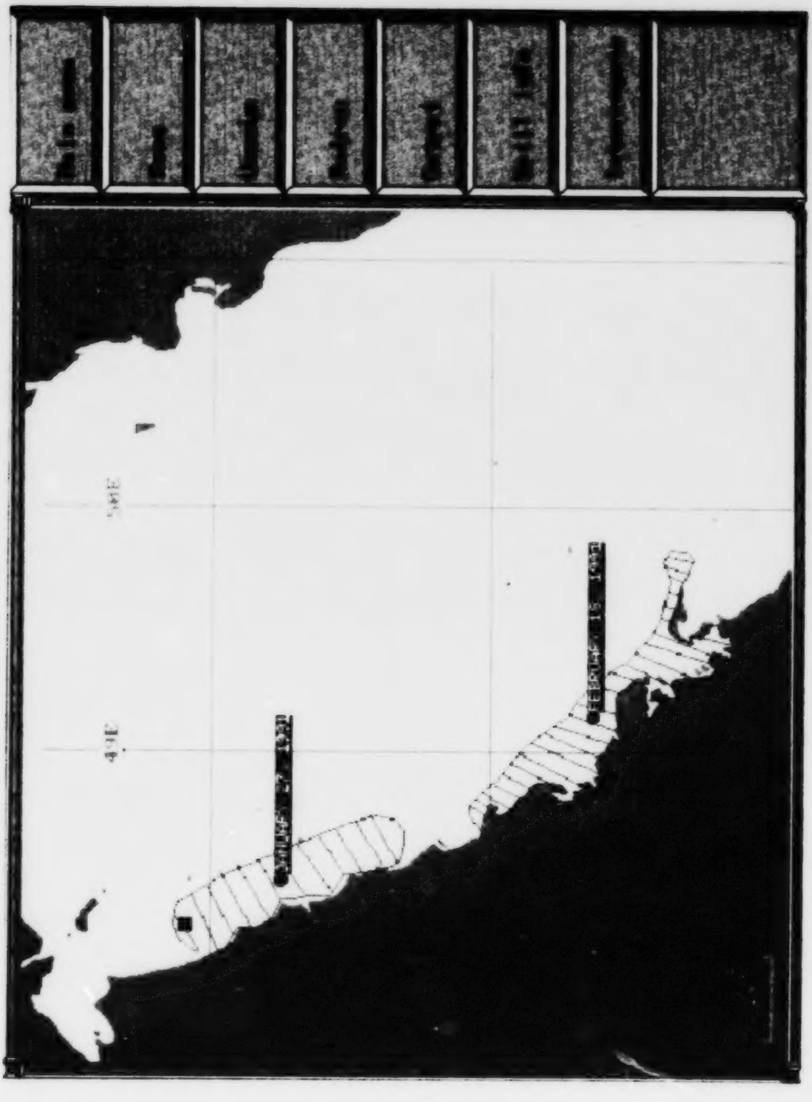
48E
49E
JANUARY 27 1991
FEBRUARY 18 1991

Figure 1 Sketch of the Mina Al Ahmadi spill on January 27, 1991 based on a Pentagon Press briefing from General Schwarzkopf and overflight observations on the spill on the morning of February 18, 1991 provided by the International Interagency Oil Spill Assessment Team.

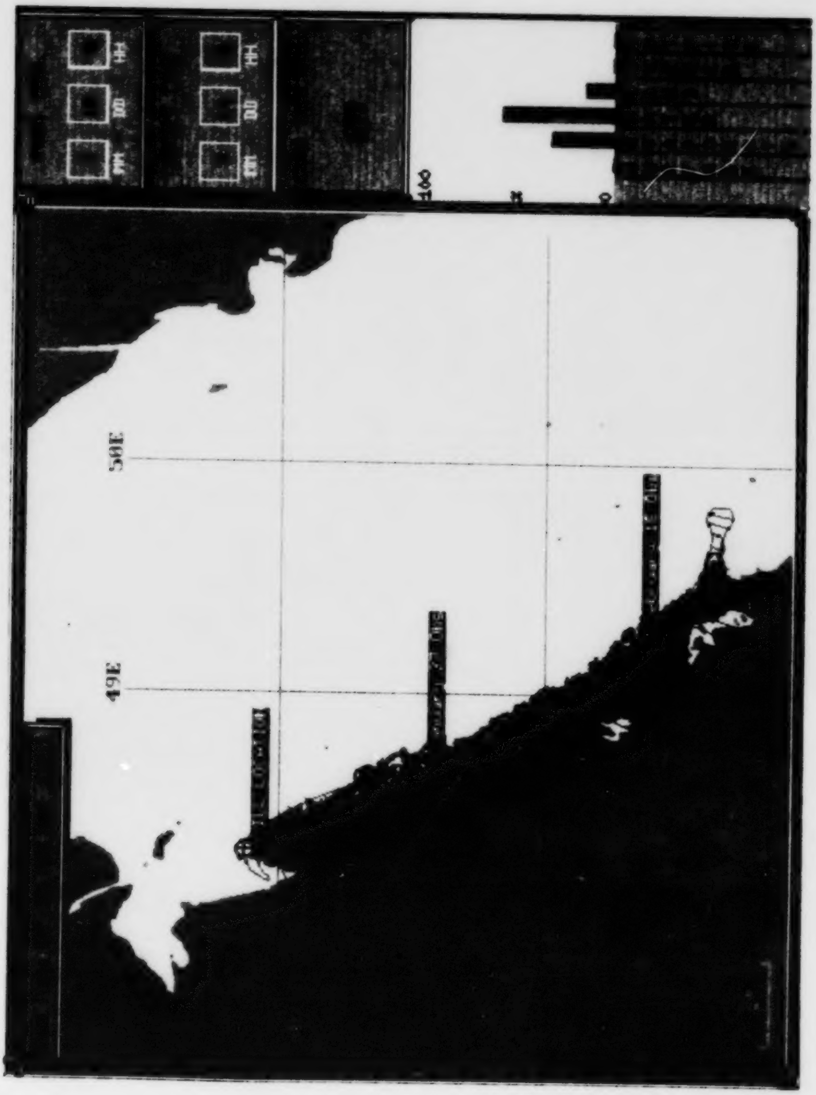

Figure 2 Comparison of oil spill model predictions with the aerial observations on February 18, 1991.

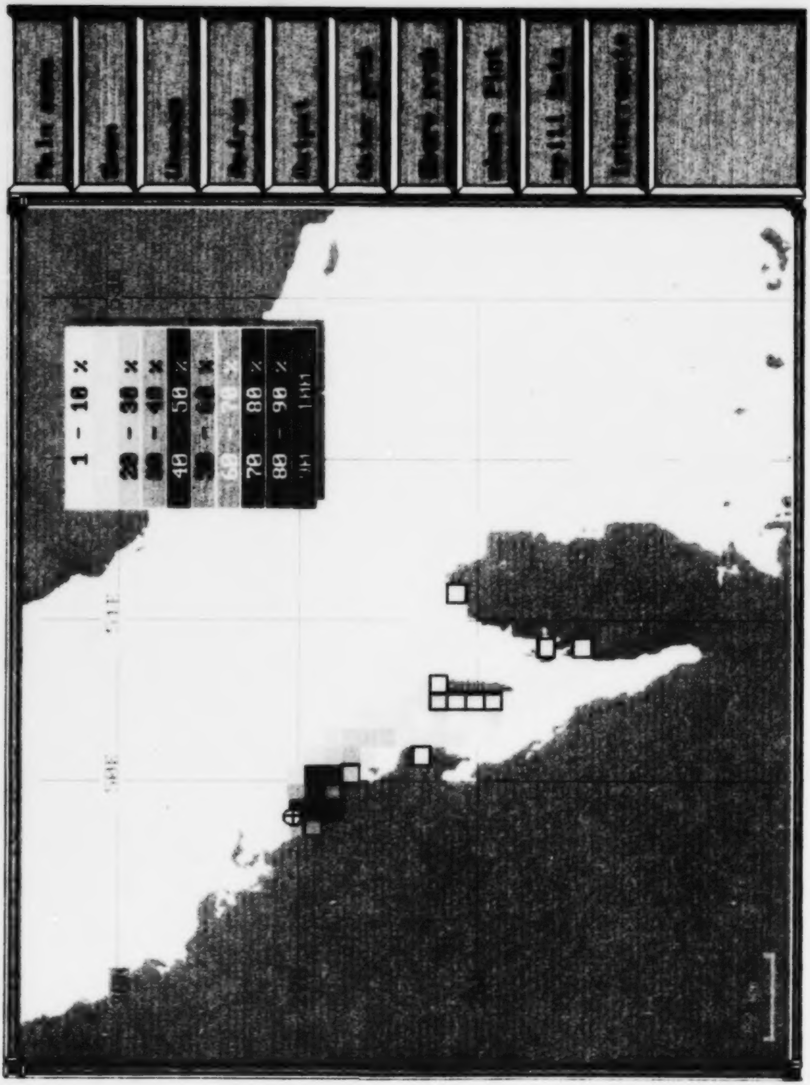
1 - 10 %
20 - 30 %
30 - 40 %
40 - 50 %
50 - 60 %
60 - 70 %
70 - 80 %
80 - 90 %
90 - 100 %
51E
50E

Figure 3 Stochastic simulations for a spill site located 10 km east of Jubayl, Saudi Arabia

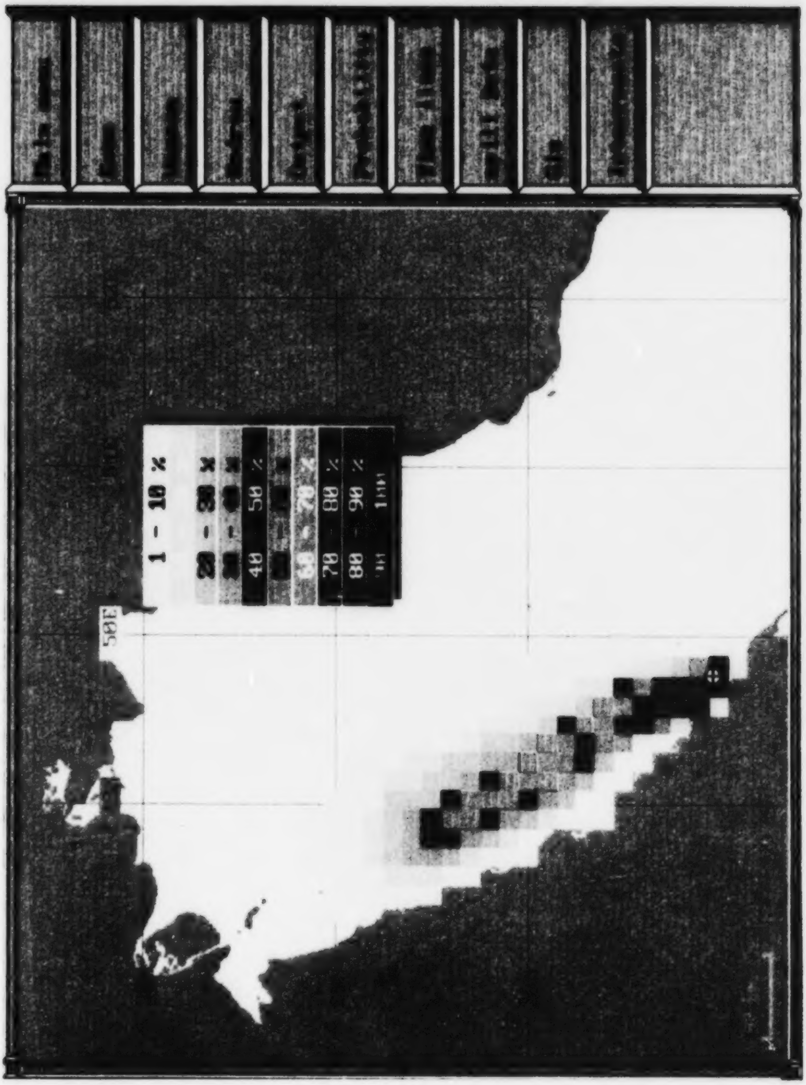
50E
1 - 10 %
20 - 30 %
40 - 50 %
60 - 70 %
70 - 80 %
80 - 90 %

Figure 4a Receptor mode calculation of the avenues of vulnerability of the Jubayl, Saudi Arabia industrial facility: probability of oil impacting surface waters

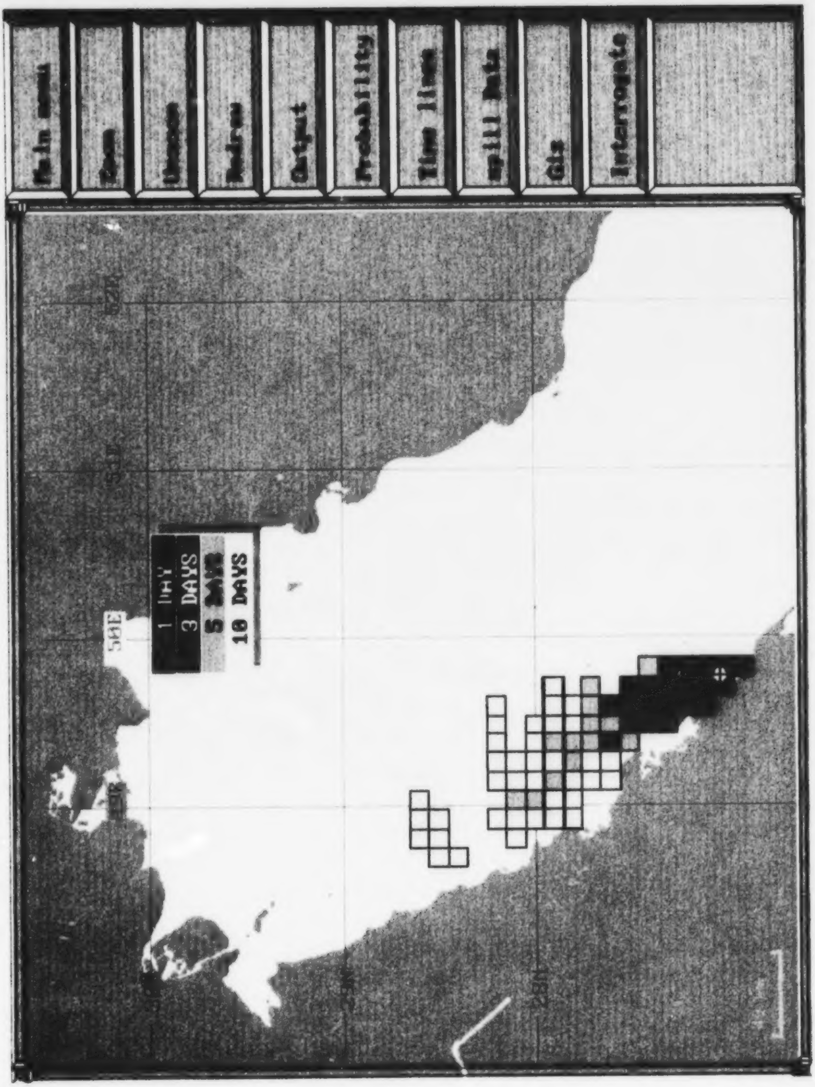
Main menu
Zoom
Unzoom
Redraw
Output
Probability
Time lines
Spill Data
Gis
Interrogate
1 DAY
3 DAYS
5 DAYS
10 DAYS
52E
51E
50E
27N
28N

Figure 4b Receptor mode calculation of the avenues of vulnerability of the Jubayl, Saudi Arabia industrial facility: minimum number of days before oil reaches the facility.

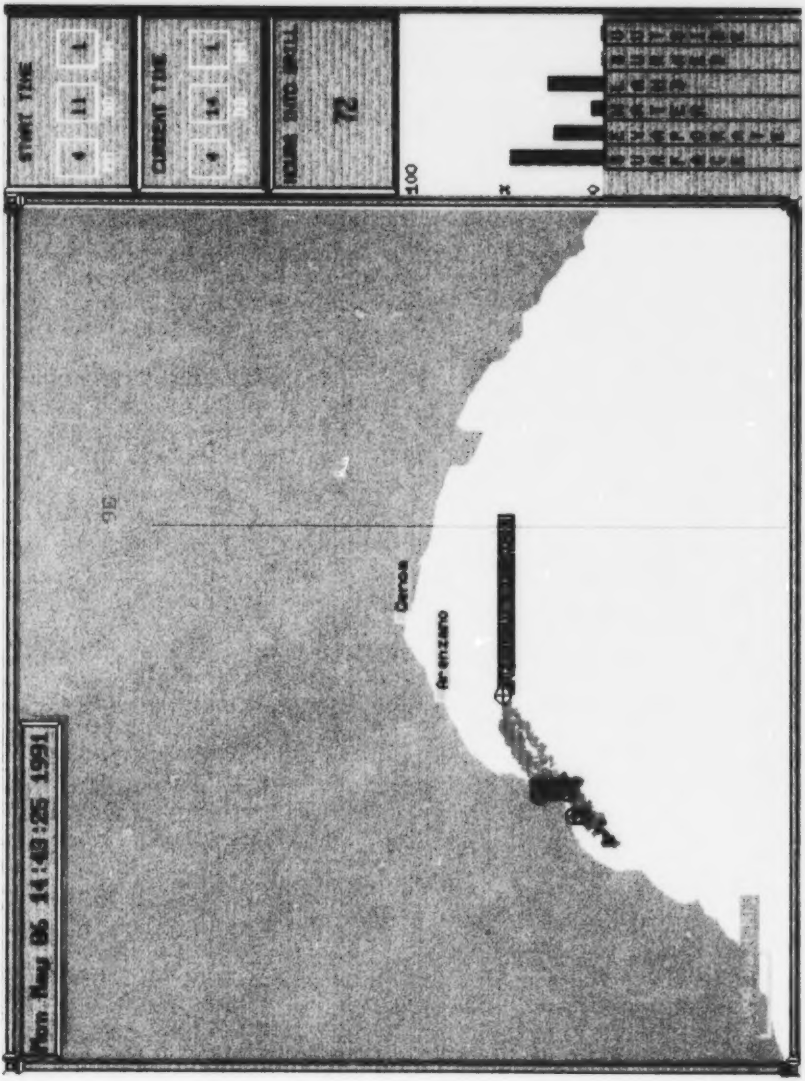
START TIME
4 11 1
CURRENT TIME
4 14 1
HOURS INTO SPILL
72
100
%
0
Genoa
Arenzano
Mon May 06 14:48:25 1991

Figure 5a Model predicted trajectory for the Cyprus *Haven* spill three days after the release from spill sites 8 and 2.5 km south of Arenzano, Italy. Spill release dates are April 11 for the offshore site. Surface circulation specified using hydrodynamic model predictions.

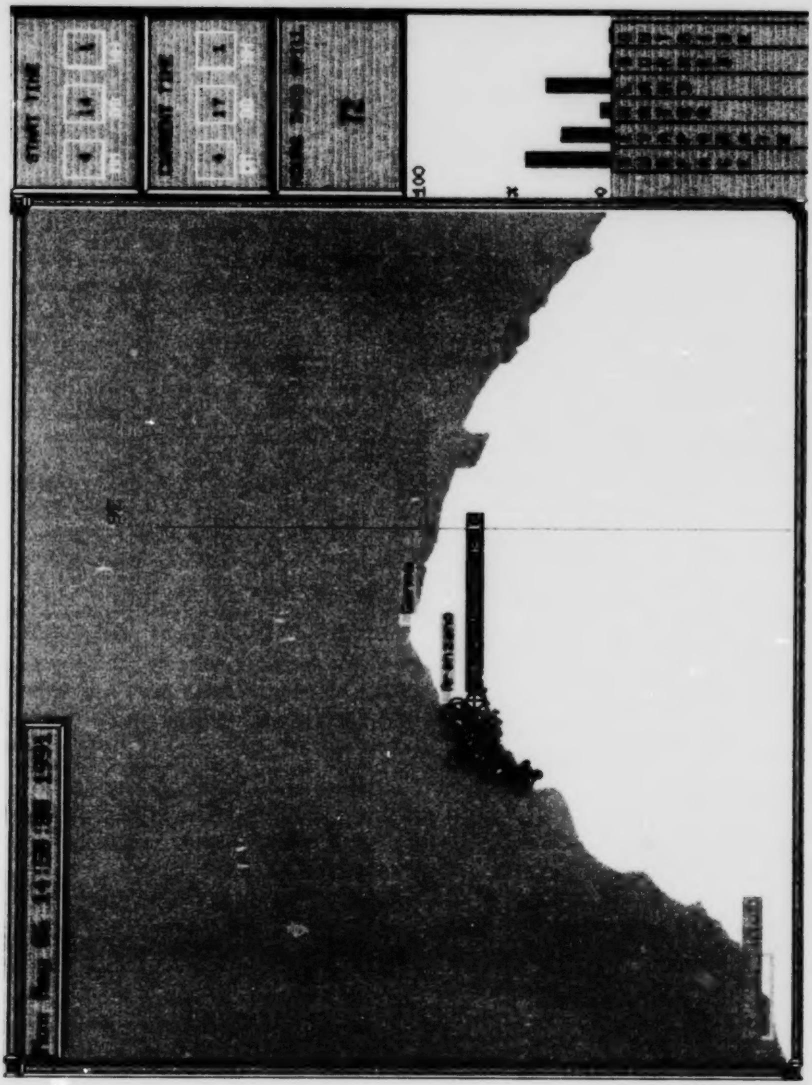
START TIME
4
14
1
CURRENT TIME
4
17
1
72

Figure 5b Model predicted trajectory for the Cyprus *Haven* spill three days after the release from spill sites 8 and 2.5 km south of Arenzano, Italy. Spill release dates are April 14 for the nearshore site. Surface circulation specified using hydrodynamic model predictions.

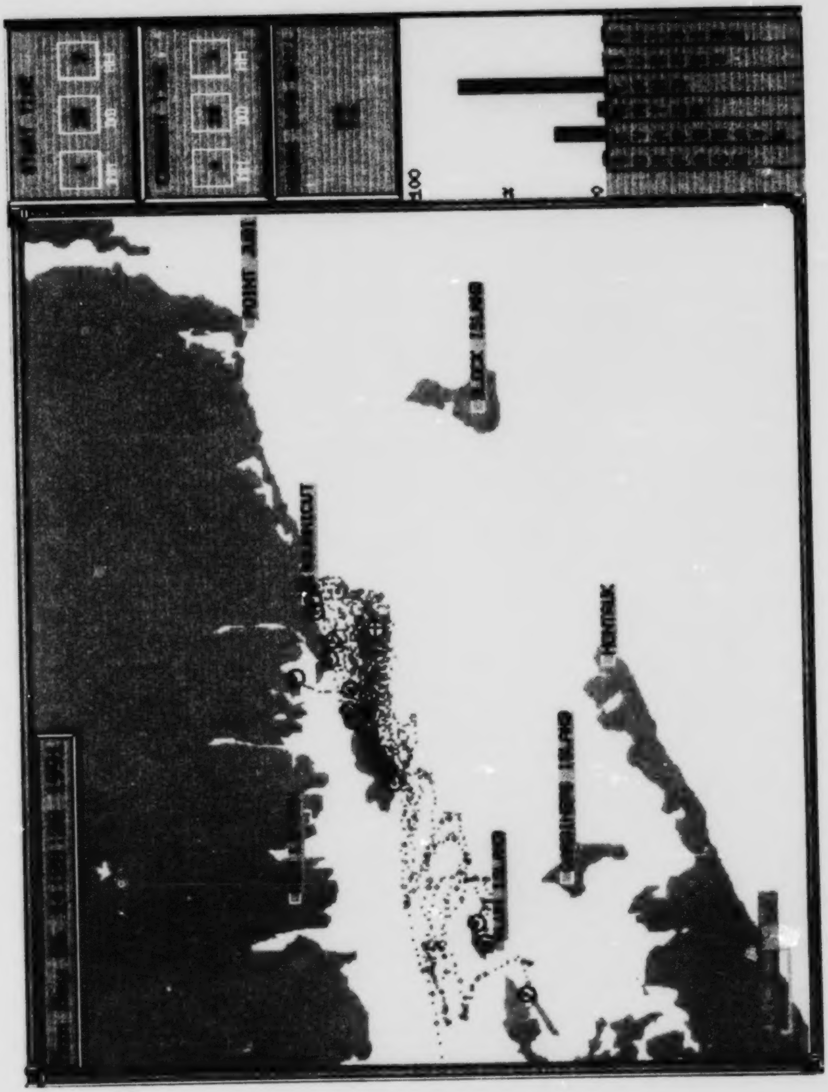
POINT JUDITH
BLOCK ISLAND
MONTAUK
GARDINERS ISLAND
PLUM ISLAND

Figure 6 Oil spill model predicted trajectories for the spill exercise scenario in Block Island Sound; 3 days after the release.

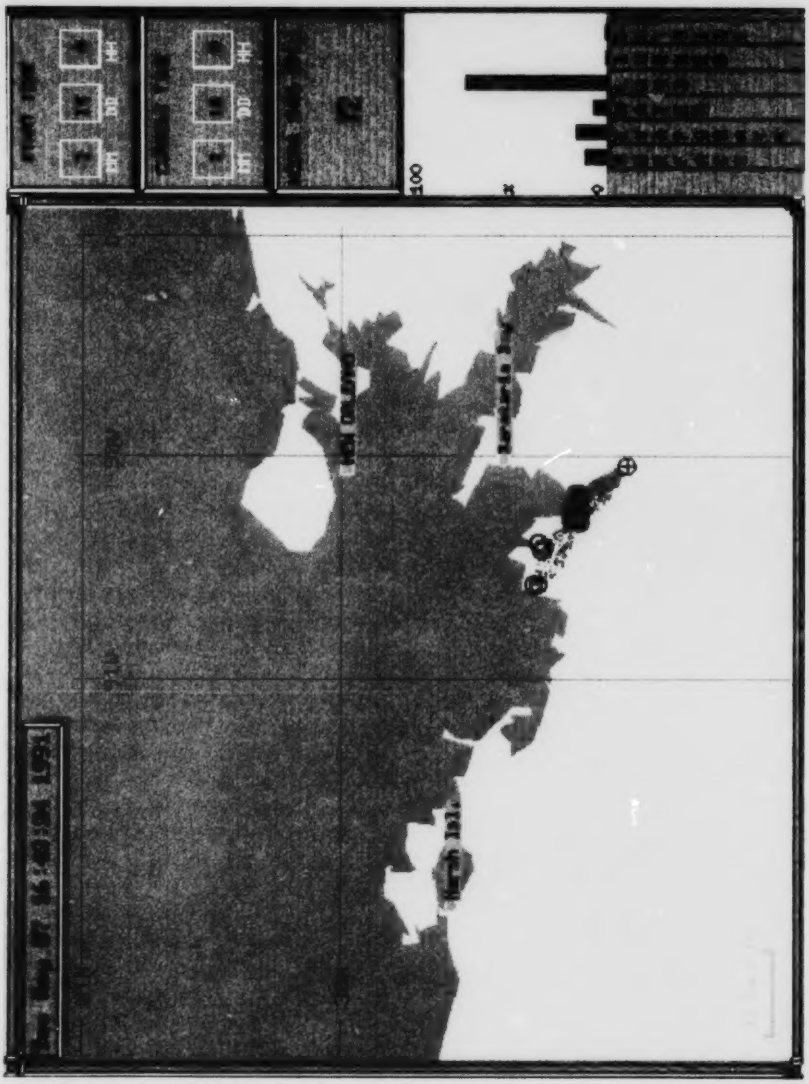

Figure 7 Oil spill model predicted trajectories for a worst case spill scenario in Gulf of Mexico; 3 days after the release.

LONG-TERM TRENDS IN THE CONCENTRATIONS OF POLYCYCLIC AROMATIC HYDROCARBONS IN THE WATER COLUMN OF PRINCE WILLIAM SOUND AND THE WESTERN GULF OF ALASKA FOLLOWING THE *EXXON VALDEZ* OIL SPILL

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Introduction

At 12:04 AM, Friday, March 24, 1989, the supertanker *Exxon Valdez* ran aground on Bligh Reef in northeastern Prince William Sound. Approximately 20 percent of the tanker's cargo, 260,000 barrels (41.3 million liters) of North Slope crude oil, was spilled into the Sound, most of it within the first few hours after the grounding.

On March 26, a storm with 70-mph westerly winds moved the oil slick toward the western part of the Sound. In the next few weeks, the oil spread among the islands and bays of western Prince William Sound and eventually into the Gulf of Alaska. Ultimately, approximately 573 km of shoreline in Prince William Sound and 1,178 km of shoreline in the Gulf of Alaska were oiled to some degree by the spilled oil. On the day after the spill, Exxon initiated an intensive monitoring program to measure the concentrations and distribution of the spilled petroleum in the water column.

Water samples were collected and analyzed from many locations and water depths throughout Prince William Sound and the western Gulf of Alaska. Sampling was performed periodically from March 27, 1989 through March 6, 1990. These surveys were intended to provide a basis for an assessment of potential effects of the spilled oil on the marine plants and animals living in the water column of the Sound and the adjacent Gulf of Alaska.

Materials and Methods

Seventeen field surveys to 110 sampling stations in Prince William Sound were performed between March 27, 1989 and March 6, 1990. An additional 95 stations were sampled during 6 field surveys to nearshore and offshore waters of the Kenai Peninsula, Lower Cook Inlet and Kodiak Island between April 11 and August 29, 1989. Most sampling stations were in areas where the oil drifted in the weeks after the spill. However, 10 stations were selected in the eastern and northern portions of Prince William Sound away from the trajectory of the spilled oil. These stations served as background stations. A total of 1,683 water column samples (plus 737 quality control samples) were collected and analyzed for petroleum-derived polycyclic aromatic hydrocarbons (PAH). An additional 3,415 water samples (plus 1,697 quality control samples) were collected and analyzed for volatile organic hydrocarbons, individual and total alkanes, and total petroleum hydrocarbons.

Water samples were collected from the water surface, just below the water surface, and from several depths between 1 and 42 m below the water surface, depending on the survey, a depth interval believed to be sufficient to characterize oil contamination that might be present in the upper water column. Many of the surface water samples were collected in sheens, and were intended primarily for characterization of the chemical composition of the PAH assemblage in sheen material and not for quantitative assessment of the amount of oil per unit area of the sea surface.

All water samples were collected, preserved, stored, and transported by using well-established procedures. Rigorous quality assurance and quality control procedures were used in all phases of the program and included strict chain-of-custody procedures to ensure sample integrity from the time of collection through analysis in the laboratory and reporting of the final data. Water samples were preserved in the field by acidification with 5 ml/l of a 1:1 solution of HCl in distilled water. Samples were stored at 4°C in the dark and extracted within 5 days of delivery to the analytical laboratory. Sample extracts were analyzed within 40 days of extraction.

For analysis of individual and total polycyclic aromatic hydrocarbons, water samples were extracted by a modification of EPA SW-846 Method 3510. PAHs were analyzed by gas chromatography with quantification by mass spectrometry in the selective ion monitoring mode. The gas chromatograph was equipped with a 25- to 30-m silica capillary column with a DB-5 bonded phase. The gas chromatograph capillary column fed directly into the ion source of the mass spectrometer operating at 70 eV (nominal) electron energy in the electron impact ionization mode. The reporting limit for water samples was 10 ng/l for individual PAHs.

Results

PAHs are composed of two or more fused (sharing two carbon atoms) benzene rings and are derived from petroleum and from combustion of organic material (Neff, 1979). The target analytes in this study were naphthalene through benzo(g,h,i)perylene as well as the alkyl homologues of naphthalene, fluorene, phenanthrene, dibenzothiophene, and chrysene. Alkyl PAH are more abundant in crude oil than in pyrogenic sources of PAH, and therefore, are particularly useful for identifying sources of PAH in environmental samples.

Average concentrations of PAHs in the offshore water column of Prince William Sound reached a peak in April (Figure 1). The highest mean concentration of PAH at all primary stations combined (stations where the oil was known to have drifted) was 0.22 µg/l and was reached about 1 month after the spill. Mean concentrations of PAH at background stations remained between 0.024 and 0.078 µg/l for the year after the spill. The apparent very slight elevation in the average concentration of total PAHs in seawater from background sites at the time of the second and third field surveys in April was due to four samples (two from each survey) containing much higher concentrations of total PAHs than other samples from all background sites.

These water samples from background sites may have been contaminated by microtarballs or bilge washings from the survey vessel. The PAH assemblages in them had characteristics of both a light refined oil and a pyrogenic (engine exhaust) source. Thus, the results of the analysis of water samples from background sites both north and east of where the spilled oil drifted provide strong evidence that there was not widespread contamination of the water column throughout Prince William Sound even for a short period after the spill.

As expected, the highest concentrations were in bays and near-shore waters of islands in western Prince William Sound where large amounts of oil drifted in the first few weeks after the spill. Highest concentrations were in surface water samples and PAH concentrations decreased with depth below the water surface (Figure 2). The average concentration of total PAH in samples from the water surface at primary stations reached a peak of 0.88 µg/l in late April, 1989. The average concentrations of total PAH in subsurface water seamples never exceeded 0.2 µg/l. The highest concentrations of PAH in single water samples recorded in these surveys were for surface water samples from Northwest Bay (8 to 29 µg/l), Bay of Isles (7 µg/l) and Herring Bay (6.8 µg/l). These samples probably contained small amounts of sheen or mousse material. The distribution of PAH in the water column of these heavily-oiled bays was similar to that for all the primary stations combined (Figure 3). Although the concentration of total PAH reached a peak of just over 7 µg/l on the water surface of the Bay of Isles in April, water samples collected at several depths below the water surface never contained contained more than 0.73 µg/l total PAH.

Of the 1,683 water samples collected from Prince William Sound and the western Gulf of Alaska for PAH analysis, 13 surface water samples were heavily contaminated with mousse or sheen material and were not included in the averages for distribution of PAH concentrations in the water column. Of the remaining samples, 27 samples (1.6%) contained more than 1 µg/l total PAH; 385 samples (23%) contained between 0.07 and 0.99 µg/l total PAH, and 1,258 (75%) contained less than 0.07 µg/l total PAH (Figure 4).

Following stranding of oil on the shores of western Prince William Sound and the Gulf of Alaska, oil was repeatedly washed off the shore by storms and high tides. This oil was weathered and was present on the water surface as sheens or mousse. A typical sheen from the Bay of Isles on the east coast of Knight Island in Prince William Sound (the sample containing 7.2 µg/l shown in Figure 3) contained primarily weathered oil (Figure 5). This figure shows the ratio of each PAH to C_3-phenanthrene. In comparison to the PAH profile of the North Slope crude oil (the spilled oil), the surface sheen oil was depleted in naphthalenes and the less alkylated fluorenes. It was enriched in C_1- through C_3-dibenzothiophenes.

Water samples collected from 3 and 30 m directly below the sheen contained a different PAH composition than the sheen. The water column samples, particularly the sample from 3 m, were not as depleted in naphthalenes as the sheen sample. In fact the 3-m sample was enriched, compared to North Slope crude oil, in C_3- and C_4-naphthalenes and the 30-m sample was enriched in C_4-naphthalenes. Both subsurface water samples were enriched in phenanthrenes and dibenzothiophenes.

Water samples were collected in Morning Cove on Ragged Island off the coast of the Kenai Penninusua on August 25, 1989, immediately after a summer storm. Samples from the water surface contained large amounts of mousse that had just washed off the shore. An analysis of the PAH profile of the mousse and water samples collected at depths of 1 and 9 m below the mousse revealed substantial dilution and fractionation of the oil with depth (Figure 6). The mousse sample was depleted in naphthalene and C_1- and C_2-naphthalenes. However, it was enriched in the more highly alkylated naphthalenes and in alkyl fluorenes, phenanthrenes, and dibenzothiophenes. The water sample collected from 1 m below the surface mousse was not depleted in naphthalene, but was depleted in alkyl naphthalenes, compared to the North Slope crude oil. Like the mousse sample, it was enriched in alkyl fluorenes, phenanthrenes, and dibenzothiophenes. A water sample from 9 m below the surface mousse contained only 0.008 µg/l total PAH. The PAH assemblage in this sample was composed primarily of naphthalene and phenanthrene, with traces of fluorene, dibenzothiophene, fluoranthene, pyrene, and higher molecular weight pyrogenic PAH.

Discussion

More than 1680 samples of water collected at locations throughout Prince William Sound and the western Gulf of Alaska at several water depths between the end of March 1989 (within a few days of the spill) and eary March, 1990 as a part of acomprehensive water quality monitoring program have revealed that the concentrations of PAHs have been uniformly very low. Highest concentrations occurred in April within 1 month of the spill, primarily on the water surface. Average concentrations then returned quickly to low, essentially background levels, where they have remained ever since.

The highest concentrations of PAH were in surface and water column samples from sheltered bays (particularly Northwest Bay and Bay of Isles, heavily oiled sites). Even in these sheltered bays, concentrations of PAH in the water column and on the water surface were quite variable in both space and time, strongly suggesting that these elevated concentrations were short-lived.

Concentrations of PAH in the water column of Prince Willian Sound and the western Gulf of Alaska following the oil spill generally have been lower than concentrations of PAH measured in the water column in the vicinity of other oil spills. For several months after a spill of refined oil products from the *Argo Merchant*, individual PAHs were present in the water column of Georges Bank at concentrations of 10 to 50 ng/l (Boehm et al., 1979). Background concentrations of individual PAHs in these waters were 1 to 10 ng/l.

Following the *Ixtoc I* blowout in the Bay of Campeche, Mexico, concentrations of particulate plus dissolved PAHs reached 2860 µg/l at a depth of 2 m near the blowout (Boehm and Fiest, 1980). At a distance of 16 km, concentrations of PAHs had dropped to 30 to 60 µg/l and, at 40 km, the average concentration of total PAHs in the water column was about 5 µg/l. The dissolved fraction of the total PAHs ranged from about 50 µg/l near the well to background concentrations (<0.1 µg/l) at 40 km.

Concentrations of total naphthalenes, fluorenes, phenanthrenes, and dibenzothiophenes in the water column at three sampling stations in inshore waters of Bermuda ranged from 3.25 to 61.7 ng/l (Ehrhardt and Burns, 1990). A sample from Three Hill Shoals did not contain detectable concentrations of any PAH. Thus, concentrations of total PAHs measured in the water column of Prince William Sound and the weatern Gulf of Alaska in the months after the spill have been lower in most cases than the concentrations of PAH measured in the water column near other major oil spills. Based on the work reported here and that of Ehrhardt and Burns (1990), background concentrations of total PAH in the water column of the ocean are in the range of 30 ng/l (parts per trillion) or less.

The results of this monotoring program show quite convincingly that PAH associated with surface sheens and mousse do not mix down into the water column to any great extent. Concentrations of PAH in the water column as little as 1 m below a surface sheen or mousse are substantially lower that the concentrations of PAH in the sheen or mousse itself. In the present investigation, no attempt was made to collect truely quantitative samples of sheen or mousse. The concentrations reported are only semiquantitative; actual concentrations of PAH in the surface microlayer probably are much higher than the concentrations reported here.

Differences in the relative concentrations of different PAH in the sheens, mousse and water column samples probably reflect oil weathering and PAH partitioning between the surface or solid phase and the water phase (Mackay and McAuliffe, 1988). The Bay of Isles sheen was collected about 1 month after the spill and was only moderately weathered. The mousse sample, collected several hundred kilometers from the spill site about 5 monts after the spill showed evidence of more substantial weathering. Weathering of crude oil usually results in a loss of the low molecular weight an unalkylated PAH and an increase in the relative concentrations of the higher molecular weight and highly alkylated PAH. Dibenzothiophenes seem to be particularly resistant to weathering.

The subsurface water column samples generally had higher relative amounts of naphthalene and phenanthrene than the surface samples. This probably is due to partitioning of this relatively soluble PAH into the water (naphthalene has a solubility in seawater of about 22 mg/l: Eganhouse and Calder, 1976). Log octanol/water partition coefficients, which are roughly comparable to oil/water partition coefficients (Mackay and McAuliffe, 1988), for the 2- through 4-ring PAH usually encountered at greatest concentration in crude oil are in the range of 3.35 (naphthalene) and 5.79 (chrysene) (Eastcott et al., 1988). Therefore, the lower molecular weight PAH partition more readily than the higher molecular weight PAH into the aqueous phase of the oil/water system.

The surprising observation from the present investigation is that a 5-month old mousse still contained substantial amounts of naphthalene and that, based on the composition of water samples collected below the mousse, naphthalene still was partitioning slowly out of the mousse. It is possible that a water-in-oil mousse is an inhomogeneous substance with small amounts of light hydrocarbons encapsulated in a matrix of heavy resin/asphaltene fractions, limiting diffusive exchange of the light hydrocarbons with the surrounding water.

Acknowledgments

This work was funded through contracts from Exxon Company USA. Major participants in this work were Arthur D. Little, Inc., America North, Inc., Battelle Ocean Sciences Laboratory, Dames & Moore, Kinnetic Laboratories, Inc., Enseco, Inc., and Geochemical and Environmental Research Group. A

more detailed technical report of this study (Neff, 1991) is available from Dr. Jerry Neff, Arthur D. Little, Inc., Acorn Park, Cambridge, MA 02140.

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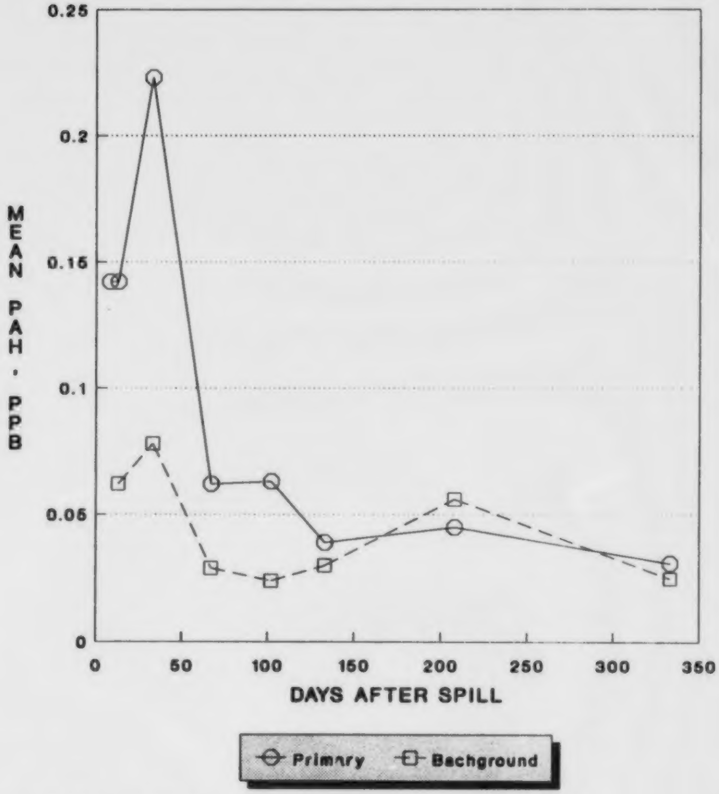

Figure 1. Mean PAH Concentrations at 25 Primary and 10 Background Stations Offshore in Prince William Sound.

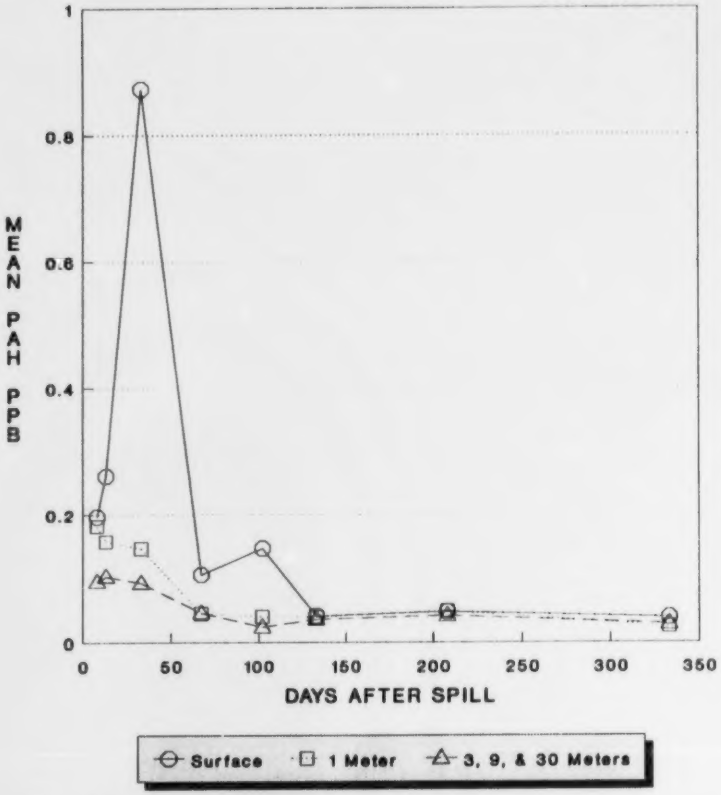

Figure 2. Mean PAH Concentrations at Three Water Depths at 25 Primary Stations in Prince William Sound.

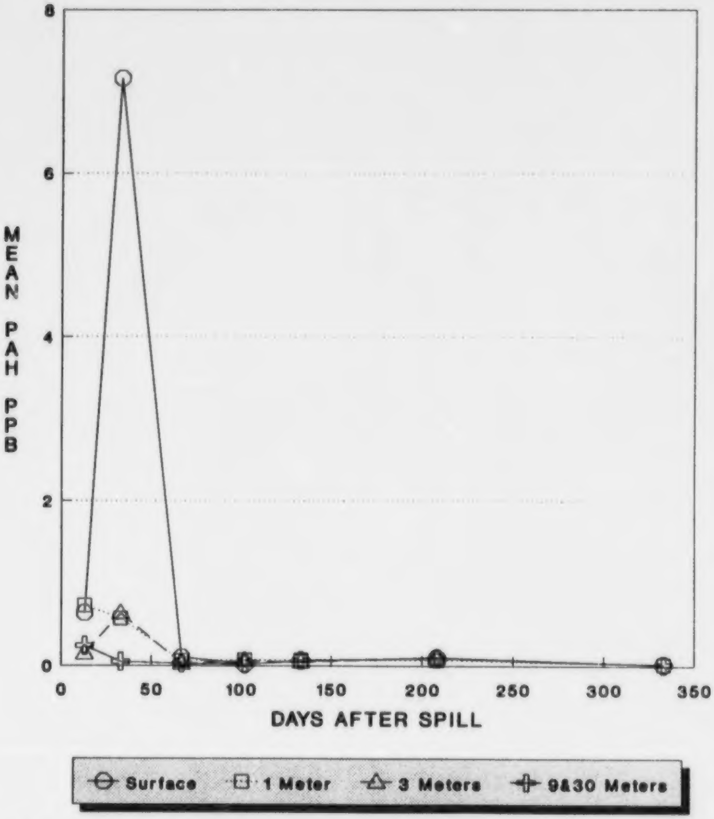

Figure 3. Mean PAH Concentrations
at Different Depths in The Bay of Isles.

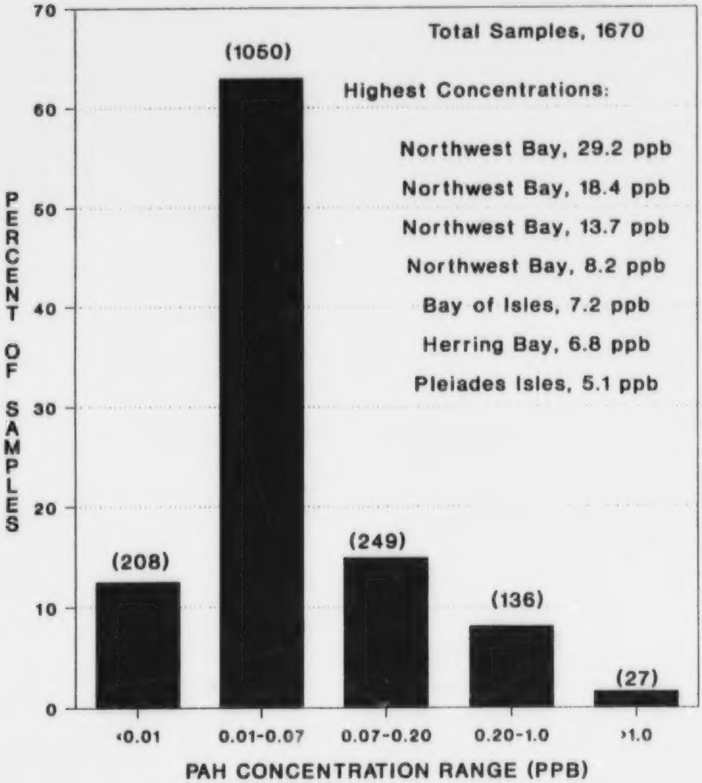

Figure 4. Distribution of PAH Concentrations in Water from Prince William Sound and Gulf of Alaska.

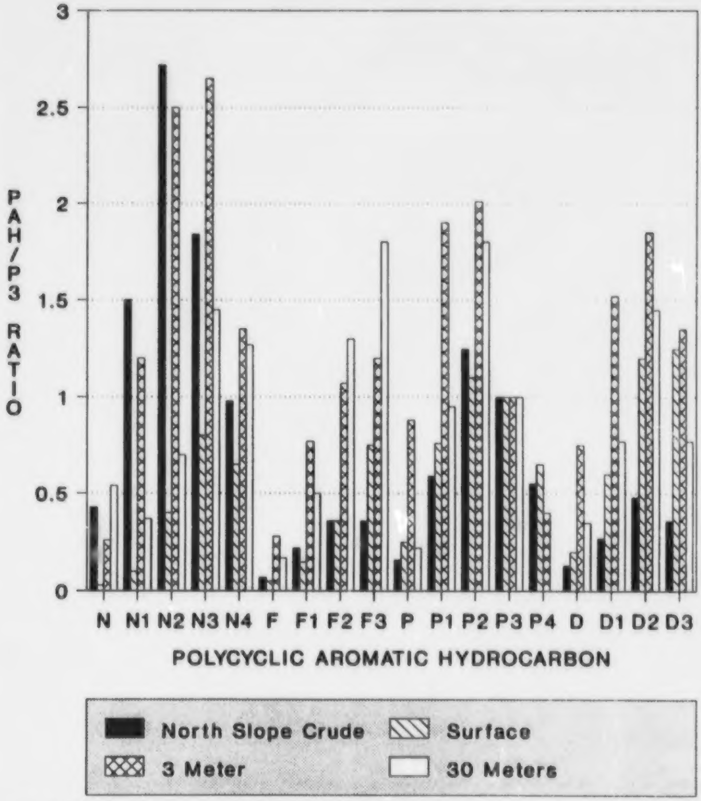

Figure 5. PAH Profiles from Bay of 'sles Knight Island, Compared to North Slope Crude Oil.

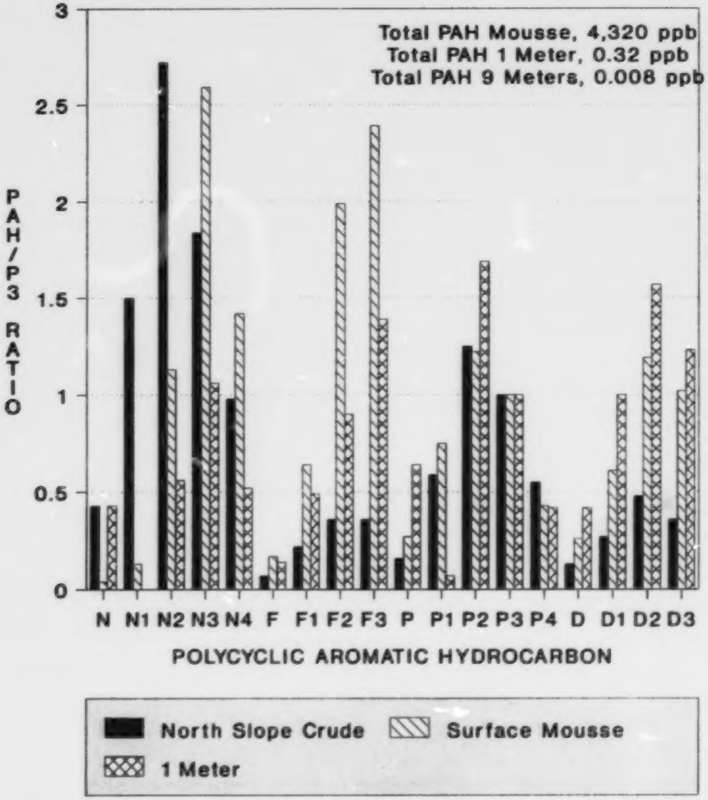

Figure 6. PAH Profiles from Morning Cove Kenai Peninsula, Compared to North Slope Crude Oil.

A HIGH-RESOLUTION COUPLED HYDRODYNAMIC AND OIL SPILL MODELLING SYSTEM APPLIED TO THE PORT OF VANCOUVER

by

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1.0 INTRODUCTION

Oil and chemical spill models designed for emergency response, for contingency planning, and for risk analysis in coastal waters must incorporate accurate currents into the transport algorithms in order to give meaningful results. This need arises because the spatial variability in currents is large, and the distribution of the spilled commodity depends to a large degree on the horizontal shear in the current field. Moreover, tides are generally important in determining the currents, and the dispersion patterns depend on the phase of the tide at which the spill occurred.

In many coastal areas, absorption or adherence of the spilled material to shorelines will also be a dominant process in determining the fate of the commodity. Predicting the sections of the shoreline contacted by the spill requires high resolution of the shoreline, the bathymetry and the currents.

SPILLSIM is a generalized spill model developed by Seaconsult Marine Research Ltd. combining a number of high-resolution hydrodynamic models coupled with a spill motion and fate module that yields the volume distribution of the material as a function of time after a spill. In areas where both horizontal and vertical density variations are small, currents are calculated using two-dimensional time-varying barotropic models (Hodgins, 1977). Where runoff produces strong density gradients, stratified flow models formulated either in terms of two layers (Hodgins, 1979; Stronach, 1981; Stronach et al., 1988), or in three-dimensions (Hodgins, 1977; Backhaus, 1985; Crean et al., 1988; Stronach, 1991) are introduced into the system.

The spill module incorporates such factors as transport by currents, diffusion, surface spreading, evaporation, vertical dispersion, and emulsification. It also includes volume losses to shoreline cells, volume fluxes through open boundaries, and volume losses from mechanical recovery.

The model formulations are described in this paper, together with an application of a barotropic current model (C2D - denoting currents in two dimensions) and the spill model to the Port of Vancouver, British Columbia.

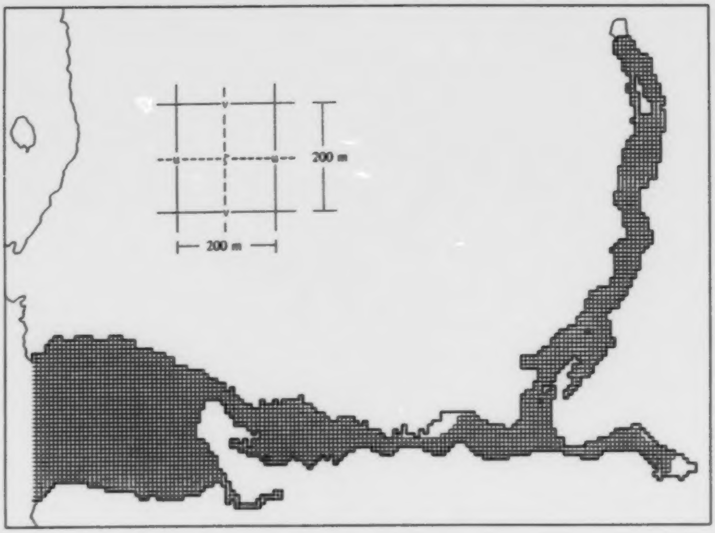


Figure 1 The 200-m grid used for hydrodynamic and oil spill modelling in Burrard Inlet.

This application was part of a risk analysis for petroleum-based commodities moving through the port. Because many of the targets in the port are small, and situated along the shoreline, a high degree of spatial resolution in the oil dispersion modelling was required to give a representative damage assessment for a particular accident scenario. This requirement demanded, in turn, high resolution and accurate modelling of the tidal currents throughout the inlet. The risk analysis is described in a companion paper by Hodgins et al. (1991).

2.0 PORT OF VANCOUVER MODEL FOR BAROTROPIC FLOWS

The surface circulation of Burrard Inlet is governed mainly by the tides and the shape of the inlet, including Indian Arm. Because the fresh water runoff into the inlet is low (the Indian River, with a peak discharge of about 100 m^3/s, is the only major source), and tidal mixing through First Narrows and Second Narrows is strong, vertical stratification is generally weak. Consequently the variations in the tidal currents affecting the dispersion of floating spills can be calculated from a barotropic two-dimensional model.

With some approximation wind-driven currents can be added vectorially to the tidal fields.

2.1 Model Formulation

C2D is a numerical current model based on conservation equations for mass and momentum. The mass conservation equation defines the time-dependent rate of change of sea surface elevation at any location as a function of the flux of water in both horizontal directions past that point:

$$\frac{\partial \zeta}{\partial t} + \frac{\partial ud}{\partial x} + \frac{\partial vd}{\partial y} = 0 \qquad (1)$$

The momentum equations, one for each spatial dimension, define the temporal rate of change of horizontal velocity in terms of non-linear horizontal velocity gradients, hydrostatic pressure gradient, Coriolis force, and bottom stress. In the x-direction (visualized as positive to the east):

$$\frac{\partial u}{\partial t} + u\frac{\partial u}{\partial x} + v\frac{\partial v}{\partial y} + g\frac{\partial \zeta}{\partial x} - fv + K_f\frac{u(u^2+v^2)^{1/2}}{d} = 0 \qquad (2)$$

with an equivalent equation for the y-direction.

In these equations, ζ is the surface elevation about mean sea level (m); u is the x-component of current (m/s); v is the y-component of current (m/s); d is total water depth (m); t is time (s); x is horizontal distance (positive to the east) (m); y is horizontal distance (positive to the north) (m); g is gravitational acceleration (9.81 m/s^2); f is the Coriolis parameter ($1.46 \times 10^{-4} \sin \phi$) (Hz); ϕ is the central latitude of the model grid (rad); and K_f is the bottom friction coefficient (dimensionless). The friction coefficient is typically of the order of 0.003 but may be several times greater in very shallow areas.

The partial differential equations are solved using a fully implicit finite difference scheme in a manner suggested by Leendertse (1967) and later tested by Hodgins (1977). The model was shown (Hodgins, 1977) to be unconditionally consistent with the differential equations and to be second-order accurate (i.e., to have truncation errors of $O(\Delta t^2, \Delta x^2, \Delta y^2)$). The one-dimensional non-linear equations without frictional dissipation are analytically unconditionally stable.

For the application to Burrard Inlet, with strongly non-linear flow fields, horizontal eddy viscosity terms are added to model horizontal momentum diffusion produced by turbulence:

$$\frac{\partial u}{\partial t} = K_H \cdot \left[\frac{\partial^2 u}{\partial x^2} + \frac{\partial^2 v}{\partial y^2}\right] \qquad (3)$$

where K_H is the horizontal eddy diffusion coefficient (m^2/s).

2.2 Application and Verification of C2D

The model was applied to the inlet on a 200-m mesh (Fig. 1) providing good resolution of shoreline features, flood-dry plains, and the bathymetry. Flood-dry plains were defined to dynamically model the periodic exposure of tidal mud flats, which are important for determining the flow field, and which constitute sensitive biological habitats. The open western boundary, along a line between Point Atkinson and Point Grey, was forced with tidal information from GF7, the barotropic model of the Straits of Georgia and Juan de Fuca (Crean et al., 1988). Solutions for tidal currents were obtained with a time step of 60 s. The friction coefficient $K_\xi = 0.0025$, and the horizontal eddy diffusion coefficient, K_H was set at 5 m^2/s. The model was initialized from rest ($u=v=\zeta=0$) using a spinup period of 24 hours, and run for 30 days following spinup.

The boundary condition was constructed from a reconstitution of 24 principal tidal harmonic constituents as determined from 10 grid points of the GF7 barotropic tidal model (Crean et al., 1988). The tidal elevation was interpolated in space from the GF7 grid points on a 2-km spacing to the C2D boundary points.

The tidal mud flats in Burrard Inlet tend to be important natural habitat areas. In Fig. 1 they are indicated by the un-hatched sections within the model domain. The largest areas are just east of Second Narrows (including Maplewood Mudflats) and at the extreme eastern end of the harbour (Port Moody). To model circulation correctly in these regions, each of these special grid cells was checked at each time step to determine if the water level had fallen below a minimum threshold (i.e., effectively dry). Current velocity was set to zero at all dried grid cells until the water level at adjacent cells rose above the minimum threshold. Each 200-m by 200-m cell was treated independently for a realistic simulation of the flooding and drying process.

Modelled tidal predictions were verified using tide gauge data for water level variations, and against the Vancouver Harbour Tidal Current Atlas (CHS, 1981). Excellent agreement between C2D- and CHS-predicted elevations was obtained. Figure 2 shows one example of the comparison for two of the gauges: Vancouver (in the vicinity of Coal Harbour) and Port Moody. The characteristic under-prediction between the 10th and the 18th of September is a product of the GF7 boundary condition, and not of the model formulation.

The current atlas summarizes the available information on flows in the harbour, and provides semi-quantitative pictures of the current velocity and pattern at 12 stages of an average tide. The maps are based on interpretation of a limited series of drogue measurements. The C2D predicted current vector maps agree reasonably well with the atlas maps. For example, at three hours before turn to ebb (Fig. 3) two gyres are present in the main part

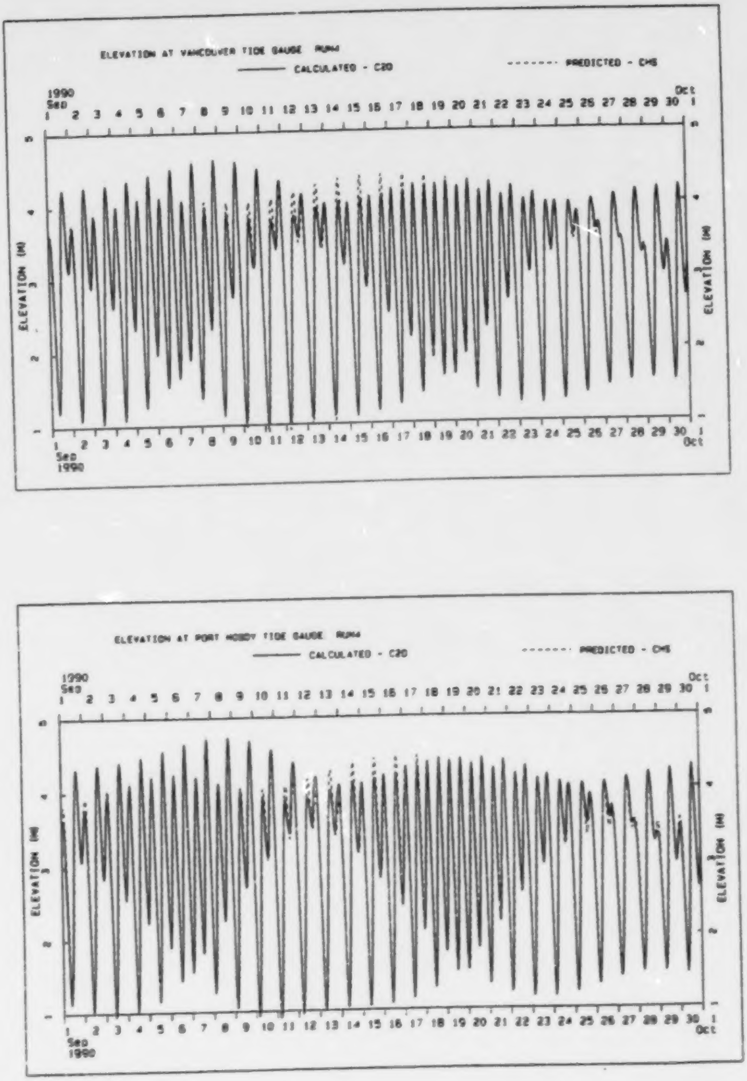


Figure 2 Comparison of C2D modelled and CHS predicted tidal water levels at the Vancouver and Port Moody gauges.

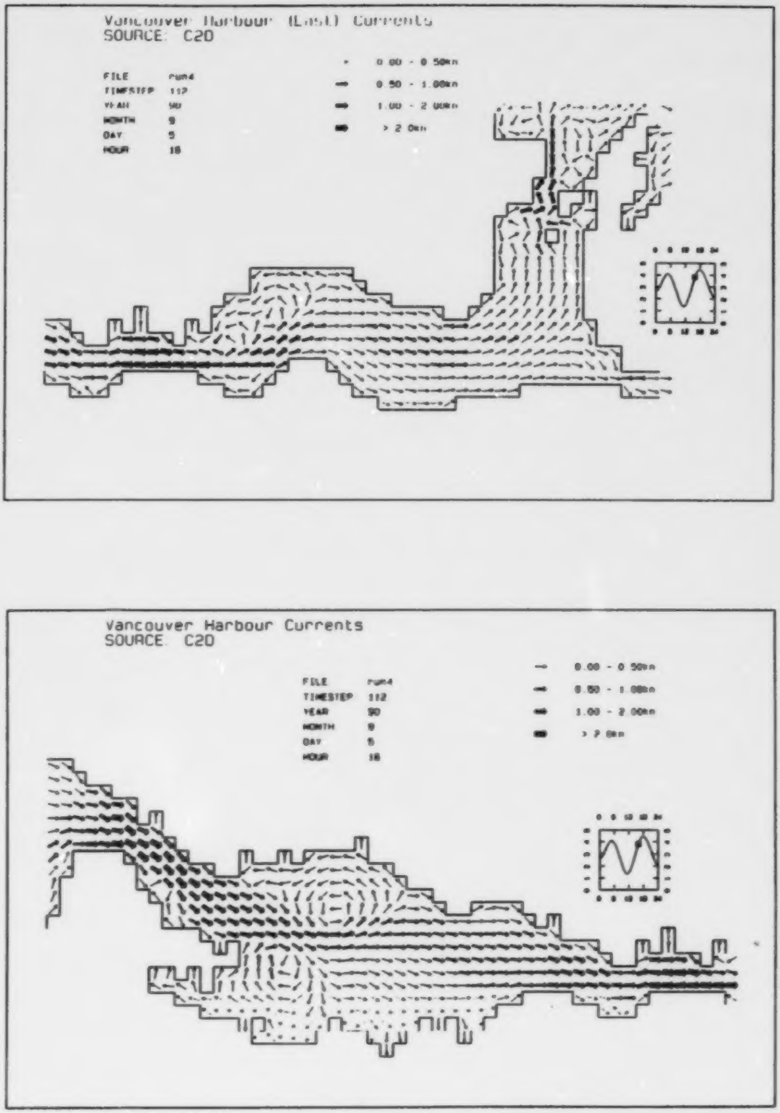

Vancouver Harbour (East) Currents
SOURCE: C2D
FILE run4
TIMESTEP 112
YEAR 90
MONTH 9
DAY 5
HOUR 16
0.00 - 0.50kn
0.50 - 1.00kn
1.00 - 2.00kn
> 2.0kn
Vancouver Harbour Currents
SOURCE: C2D
FILE run4
TIMESTEP 112
YEAR 90
MONTH 9
DAY 5
HOUR 16
0.00 - 0.50kn
0.50 - 1.00kn
1.00 - 2.00kn
> 2.0kn

Figure 3b Tidal currents 3 h before the turn to ebb predicted with C2D.

of the harbour east of First Narrows. On the north side the flow is counterclockwise, and on the south side off the entrance to Coal Harbour the flow is clockwise. East of Second Narrows two similar reverse circulation cells are formed. Currents exceed 2 knots in both First and Second Narrows. All of these features are present in the measured currents.

On the basis of this and similar comparisons throughout the tide cycle, it was concluded that the barotropic model accurately reproduces the circulation. Additional data on currents would be required to improve the model further.

During the summer months when runoff from the Fraser River stratifies English Bay and the portion of Burrard Inlet west of First Narrows, currents have been calculated using the two-layer stratified flow model GF4 (Stronach et al., 1988). A new three-dimensional stratified flow model (GF8) has recently been completed for the Straits of Georgia and Juan de Fuca. It is described in Stronach (1991) and like GF4 can be coupled into SPILLSIM for spill modelling.

3.0 MODELLING CONCEPT FOR AN OIL SPILL

The weathering processes play an important role in changing the volume and mass of an oil spill as it evolves with time. Of these processes, evaporation is the most significant (e.g. Huang and Monastero, 1982). The analytical method based on an equation for the vapour pressure as a function of both temperature and fraction evaporated (Mackay and Paterson, 1980) has been used in the present model. This approach treats the oil in two components, one denoted as the "thick" portion of the slick, and the second as the "thin" portion (Mackay et al., 1980). The other weathering processes are parameterized consistently in terms of the same two components. The factors governing the transport and dispersion of the slick are shown schematically in Fig. 4.

The spill, which may be virtually instantaneous or may last several hours or days, is divided into a time-series of discrete parcels. Each parcel has a volume and area associated with the thick and thin slick fractions; these volumes and areas change as a function of the weathering processes. Horizontal dispersion of the oil or chemical is modelled by dividing each parcel into many particles. The oil volume associated with the parcel at any time is divided equally amongst the particles in order to account for shoreline, recovery and other boundary volume losses.

The particles are dispersed by the currents independently. The advective effects are determined by mean currents, while the influence of turbulent diffusion is modelled as a random process. The spill model is solved on the same regular Cartesian grid used for the hydrodynamic modelling.

For commodities other than crude oil, the weathering processes and the dual

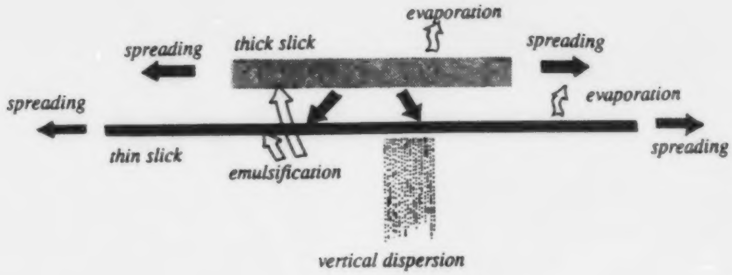


Figure 4 Schematic diagram illustrating the components of the spill motion and fate model.

slick formulation are modified to give the appropriate volume and composition changes.

3.1 Spill Model Formulation

(a) Transport and Diffusive Processes

Each particle of oil is defined by a position vector **R**(t) with location at time t given by:

$$\mathbf{R}(t) = \int_0^t (\mathbf{U}_c + \mathbf{U}')\, dt \tag{4}$$

where $\mathbf{U}_c$ denotes the smoothly varying current comprised of tidal currents, estuarine or mean currents, and wind-driven currents. The tidal and estuarine currents are known from the hydrodynamic models. In the Port of Vancouver application, the deterministic part of the wind-driven current has been formulated as $0.030\mathbf{U}_{10}$ flowing at an angle of 10° to the right of the 10-m overwater wind vector $\mathbf{U}_{10}$. The wind speed is given in m/s.

The turbulent part of the flow field **U'** arises from subgrid scale motions that are not resolved in the smoothly varying part of the flow, and from variations associated with changes in wind speed that are not contained in $\mathbf{U}_{10}$.

The integral in (4) is solved in a sequence of N discrete time steps with increment Δt, for M particles comprising each oil parcel spilled. The result is M position vectors

$$\mathbf{R}_i(N\Delta t) = \sum_{n=1}^{N} (\mathbf{U}_c(n\Delta t)\cdot\Delta t + x_n\cdot r_n); \quad i=1,2,\ldots,M \qquad (5)$$

For a particle that moves a distance which is uniformly distributed in the range (-x,...,+x) in a time step Δt, the probability of the particle being at location x at time t satisfies the diffusion equation with apparent diffusivity $D = x^2/2\ \Delta t$. Thus $|x| = \sqrt{2D\ \Delta t}$. The procedure given by (2.3) constitutes a Monte Carlo method (Bauer, 1958) where the diffusive effects of **U**' are simulated by a random walk analogy (see e.g. Tayfun and Wang, 1973) consisting of M trials each with N random displacements having magnitudes between 0 and x. r_n is a random number in the range (-1,1).

Representative diffusion coefficients are specified as a function of a length scale (Monin and Ozmidov, 1985) characterizing the turbulent process omitted from $\mathbf{U}_c$. In the Port of Vancouver, the turbulence scales are of the order of a few grid spacings (O(600) m), and the diffusion coefficient would be approximately 0.5 to 1 m^2/s. The maximum value of the random walk step would thus be about 20 m or 10% of the grid spacing for the Port of Vancouver model (Δt = 180 s).

(b) Weathering Processes

The risk analysis in the Port of Vancouver involved different commodities, including crude oil, Bunker oil, and several distilled products. The important weathering processes were spreading and evaporation. Given the low wave climate in the region, and the limited duration that the spill remained waterborne, emulsification and vertical dispersion in the water column were ignored. These process can be included in the model as appropriate.

The weathering processes are treated in terms of the volume and area of oil associated with each parcel, modelled in terms of the thin and thick slicks. The slick properties are:

Parameter	Thick Slick	Thin Slick	Units
area	a_c	a_n	m^2
volume	V_c	V_n	m^3
thickness	h_c	h_n	m
total area	$a = a_c + a_n$		m^2
total volume	$V = V_c + V_n$		m^3
per cent volume	$V_p = 100\cdot V/V_0$		%

where V_0 is the total volume contained in each parcel at $t=0$. Each of the M particles comprising one parcel thus has a volume of V/M m^3.

Spreading

Spreading is modelled following the method described by Mackay et al. (1980) expressed in terms of the change in area of each component slick with time. The calculation is initialized assuming a known thickness for the thick slick ($h_c = 0.020$ m) and the initial volume V_0. It is also assumed that the ratio of the areas is given initially by $a_n = 4\ a_c$. Then at time $t=0$, $a_c = V_0/(4h_n + h_c)$, $V_n = a_n h_n$, and $V_c = V_0 - V_n$. The thin slick thickness is treated as a constant ($h_n = 10^{-5}$ m).

Over the time step Δt the spreading of the thin slick is given by

$$\Delta a_n/\Delta t = C_1\, a_n^{1/3} \exp(-C_3/(h_n + h_c)) \qquad (6)$$

Since h_n is constant, the increase in the thin slick area requires an exchange of volume from the thick slick to the thin slick given by

$$\Delta V_n = \Delta a_n \cdot h_n = -\Delta V_c \qquad (7)$$

The spreading relationship for the thick slick is

$$\Delta a_c = C_2\, a_c^{1/3}\, h_c^{4/3}\, \Delta t - \Delta V_n/h_c \qquad (8)$$

Following this calculation the new thickness of the thick slick is updated using $h_c = V_c/a_c$. The three empirical coefficients are given in Mackay et al. (1980) as $C_1 = 1.0$, $C_2 = 150$ and $C_3 = 0.0015$.

Evaporation of Multi-component Oil Slicks

Evaporation of hydrocarbon spills comprised of several fractions is modelled by volume losses from both the thick and thin slicks. The volume change of the thick slick is based on the evaporative exposure concept described by Stiver and Mackay (1984). Denoting f_c as the volume fraction of evaporated liquid, it is defined at any time t as $df_c = H \cdot d\theta$, where

> $\theta = K_e\, t/h_c$ = evaporative exposure as a function of t, the mass transfer coefficient K_e and slick thickness h_c; and
>
> $H = P \cdot M_v/\,(R \cdot T) = \exp(A - B \cdot T_B/T)$ in which A and B are constants derived from experimental data.

For various crude oils typical values are $A = 6.3$ and $B = 10.3$. T_B is the boiling temperature (°K) which is related to the initial boiling temperature T_o, f_c, and the gradient of the distillation curve T_G by $T_B = T_o + T_G\, f_c$.

The expression for T_G is $T_G = C\ T_e/10.6$ with $T_e = 283°K$. Representative values for C are available from Mackay and Paterson (1980) for crude oil and several oil-based products.

In the above equation T is the air temperature (°K) at which the vapour pressure P is calculated, and R is the gas constant (82 x 10^{-6} atm·m^3·mol^{-1}·°K^{-1}. M_v is the molar volume of the fraction evaporating. For various oil products Mackay et al. (1980) recommend values ranging from 100 to 250 x 10^{-6} m^3/mol. The vapour pressure P is defined by

$$P = P_o \exp(-C\ f_c) \qquad (9)$$

where P_o is the initial vapour pressure.

The mass transfer coefficient K_e is given by

$$K_e = 0.001815\ (W_{10})^{0.78} \qquad (10)$$

where W_{10} is the 10-m overwater wind speed in m/s.

The volume of oil evaporated in time step Δt is thus (Mackay et al., 1980)

$$\Delta V_c = -V_c \cdot \Delta f/\ (1-f_c) \qquad (11)$$

Evaporation from the thin slick is assumed to be instantaneous reaching the limiting value f_{max} immediately, i.e.

$$\Delta V_n = -V_n \cdot (f_{max}-f_n)/(1-f_n) \qquad (12)$$

When the slick comprises only one component, the division between thin and thick fractions reduces to a single slick. The change in fraction evaporated in this slick is also as described above with the change in volume evaporated given by (11).

3.2 Boundary Conditions

(a) Shoreline Volume Loss

Shoreline cells are defined on the landward side of the solid boundary marking land from water cells. These shoreline cells are assigned an oil saturation volume depending upon their morphological composition. Generally, the amount of oil that can be absorbed and held on flat, sandy shorelines is large, whereas the volume that can adhere to rocky shorelines exposed to wave action is low. During the advection process, each particle may cross from water into a shoreline cell in one time step Δt. The volume assigned to that particle is absorbed by the beach cell, and the particle is removed from the numerical integration, until the cell is saturated. If additional particles enter the shoreline cell after it has reached saturation, these particles are returned to the adjacent water cell with their volume intact.

In this way the volume of oil retained on the shoreline during a spill simulation is accounted for in the total volume of oil at any time t. In the Port of Vancouver shoreline losses are important in determining the fate of spill commodities.

(b) Open Boundary Losses

At open boundaries the transport model is programmed so that if a particle moves across the boundary and out of the solution domain, the particle volume is lost permanently.

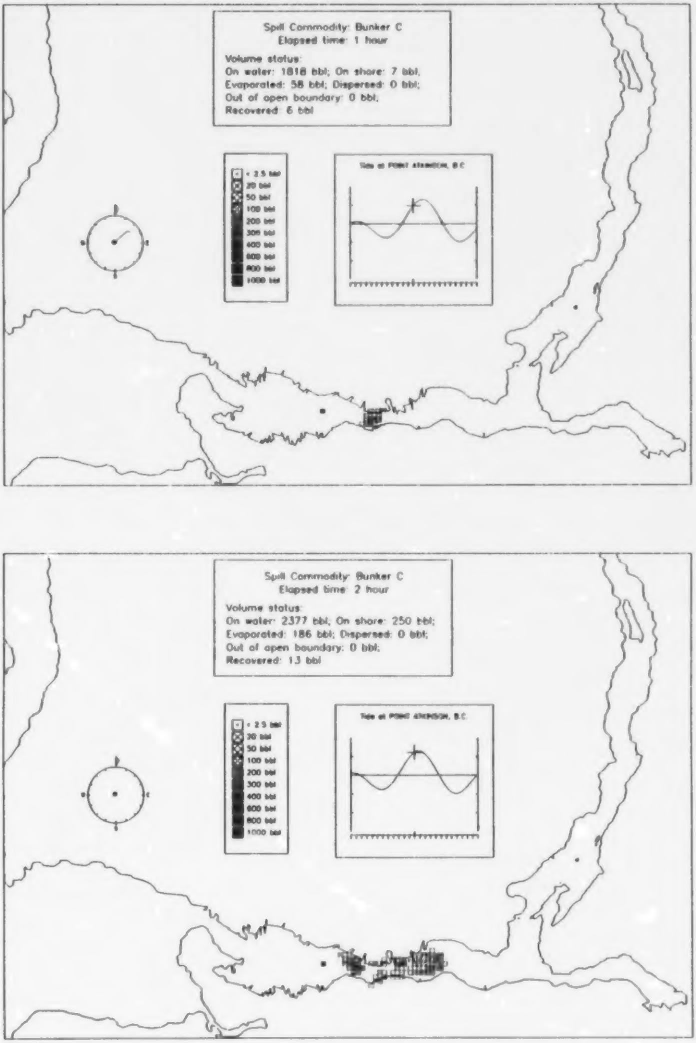
(c) Oil Recovery Mechanisms

In many oil spills, particularly in sheltered waters, booming and oil recovery operations will begin quickly after the spill occurs. The model allows considerable flexibility in specifying where and how much oil will be recovered as a function of time after the spill. In the Port of Vancouver, recovery is treated as a global volume loss to the total volume on the water being modelled. The volumes removed are specified as an input time-series, and are subtracted at the appropriate rate each time step. Other spatially-dependent algorithms can be incorporated as required.

4.0 RESULTS FOR A BUNKER SPILL IN THE INNER HARBOUR

Bunker C oil is transported through the port in relatively large quantities. Barges with capacities ranging from 500 to 1000 tonnes account for most of this movement. The spill results for a hypothetical accident near Second Narrows are discussed in this section to illustrate the modelling results. A spill of 600 tonnes distributed evenly over 4 hours has been assumed. This spill has been modelled in 4 parcels released hourly, each consisting of 400 particles. The distribution of the spill in time and the number of particles per parcel have been chosen arbitrarily.

The results are shown in Fig. 5 to 8 in terms of the volume of Bunker contained in each 200 x 200 m cell as a function of elapsed time. The tidal phase for each map is also shown. Under light winds, the first two parcels of oil move up-inlet on the rising tide (Fig. 5). At high water, as the tide turns (Fig. 6 - upper panel), Bunker oil has reached the sensitive mudflats above Second Narrows, and parcels released earlier begin to move seaward over the spilling oil. As the ebb sets in, the oil now distributed from the entrance to Indian Arm to the inner harbour, moves seaward contacting both shores (Fig. 6 - lower panel). On ebb (Fig. 7) the oil moves out through First Narrows coming in contact with Stanley Park. Eighteen hours after the spill (Fig. 8) most of the oil has been retained on the shoreline or is in the inner harbour near Second Narrows. The duration of this spill is



Spill Commodity: Bunker C
Elapsed time: 1 hour

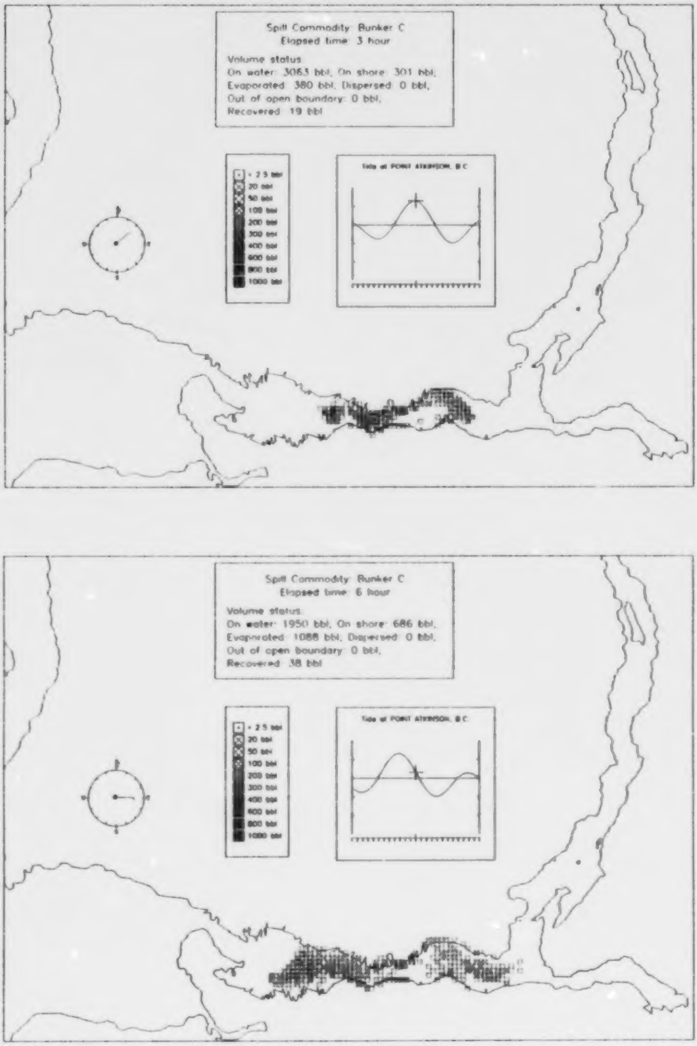
Volume status:
On water: 1818 bbl; On shore: 7 bbl;
Evaporated: 58 bbl; Dispersed: 0 bbl;
Out of open boundary: 0 bbl;
Recovered: 6 bbl

Spill Commodity: Bunker C
Elapsed time: 2 hour

Volume status:
On water: 2377 bbl; On shore: 250 bbl;
Evaporated: 186 bbl; Dispersed: 0 bbl;
Out of open boundary: 0 bbl;
Recovered: 13 bbl

< 2.5 bbl
20 bbl
50 bbl
100 bbl
200 bbl
300 bbl
400 bbl
600 bbl
800 bbl
1000 bbl
Tide at POINT ATKINSON, B.C.

Figure 5 Oil distribution 1 and 2 h following a Bunker spill near Second Narrows.


Spill Commodity: Bunker C
Elapsed time: 3 hour

Volume status
On water: 3063 bbl, On shore: 301 bbl,
Evaporated: 380 bbl, Dispersed: 0 bbl,
Out of open boundary: 0 bbl,
Recovered: 19 bbl

Spill Commodity: Bunker C
Elapsed time: 6 hour

Volume status
On water: 1950 bbl, On shore: 686 bbl,
Evaporated: 1088 bbl, Dispersed: 0 bbl,
Out of open boundary: 0 bbl,
Recovered: 38 bbl

< 2.5 bbl
20 bbl
50 bbl
100 bbl
200 bbl
300 bbl
400 bbl
600 bbl
800 bbl
1000 bbl
Tide at POINT ATKINSON, B.C.
< 2.5 bbl
20 bbl
50 bbl
100 bbl
200 bbl
300 bbl
400 bbl
600 bbl
800 bbl
1000 bbl
Tide at POINT ATKINSON, B.C.

Figure 6 Oil distribution 3 and 6 h following a Bunker spill near Second Narrows.

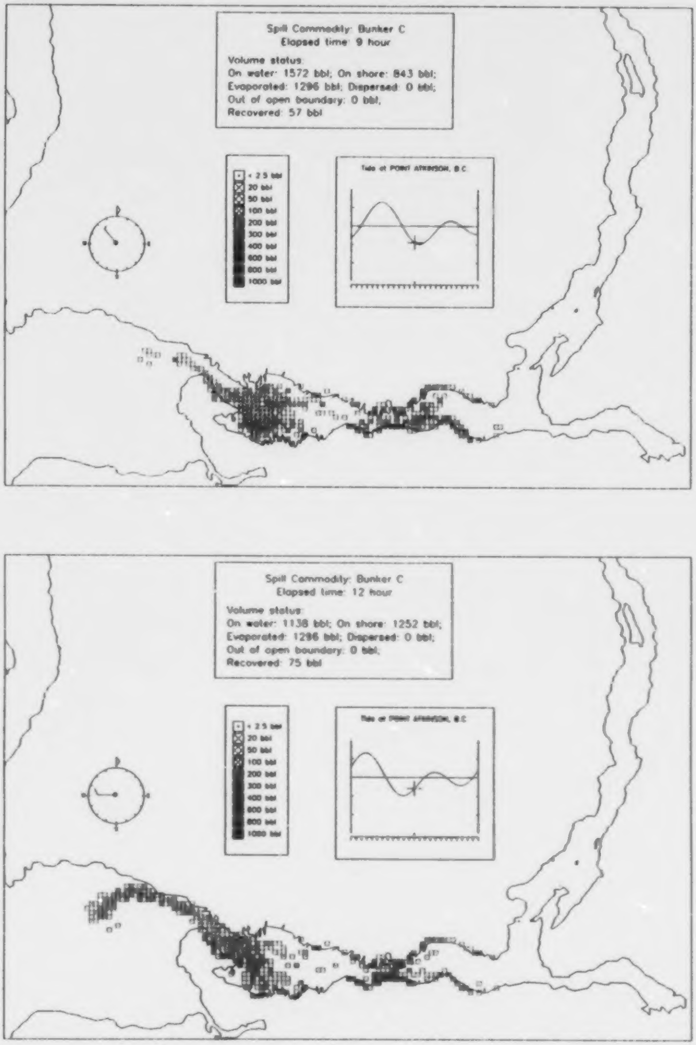

Spill Commodity: Bunker C
Elapsed time: 9 hour
Volume status:
On water: 1572 bbl; On shore: 843 bbl;
Evaporated: 1296 bbl; Dispersed: 0 bbl;
Out of open boundary: 0 bbl;
Recovered: 57 bbl
< 2.5 bbl
20 bbl
50 bbl
100 bbl
200 bbl
300 bbl
400 bbl
600 bbl
800 bbl
1000 bbl
Tide at POINT ATKINSON, B.C.
Spill Commodity: Bunker C
Elapsed time: 12 hour
Volume status:
On water: 1138 bbl; On shore: 1252 bbl;
Evaporated: 1296 bbl; Dispersed: 0 bbl;
Out of open boundary: 0 bbl;
Recovered: 75 bbl
< 2.5 bbl
20 bbl
50 bbl
100 bbl
200 bbl
300 bbl
400 bbl
600 bbl
800 bbl
1000 bbl
Tide at POINT ATKINSON, B.C.

Figure 7 Oil distribution 9 and 12 h following a Bunker spill near Second Narrows.

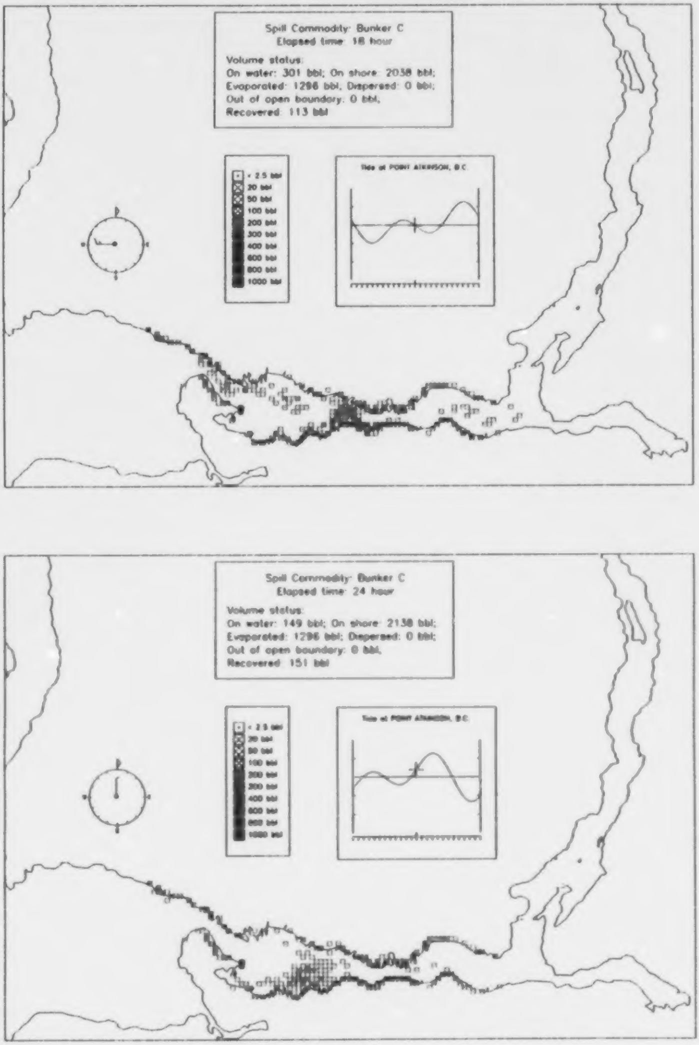

Spill Commodity: Bunker C
Elapsed time: 18 hour
Volume status:
On water: 301 bbl; On shore: 2038 bbl;
Evaporated: 1296 bbl; Dispersed: 0 bbl;
Out of open boundary: 0 bbl;
Recovered: 113 bbl
< 2.5 bbl
20 bbl
50 bbl
100 bbl
200 bbl
300 bbl
400 bbl
600 bbl
800 bbl
1000 bbl
Tide at POINT ATKINSON, B.C.
Spill Commodity: Bunker C
Elapsed time: 24 hour
Volume status:
On water: 149 bbl; On shore: 2138 bbl;
Evaporated: 1296 bbl; Dispersed: 0 bbl;
Out of open boundary: 0 bbl;
Recovered: 151 bbl
< 2.5 bbl
20 bbl
50 bbl
100 bbl
200 bbl
300 bbl
400 bbl
600 bbl
800 bbl
1000 bbl
Tide at POINT ATKINSON, B.C.

Figure 8 Oil distribution 18 and 24 h following a Bunker spill near Second Narrows.

predicted to be 32 hours at which time the volume left floating on water is 12 barrels or 0.3% of the original volume.

In terms of the original spill volume, 60% ended up on shore, 35% evaporated, and in this simulation, 5% was recovered on water. No oil crossed the open boundary into the Strait of Georgia.

4.0 CONCLUSIONS

As shown in these examples SPILLSIM provides apparently realistic simulations of the evolution and fate of a spilled. It appears that such important aspects as evaporation and shoreline absorption are properly treated by the model. Moreover, the balance between tidal and wind-driven currents is also an important factor governing the fate of spilled materials. Within the limitations of available oceanographic data, the hydrodynamic model used to provide tidal currents to the spill model accurately reproduce actual flows, and consequently the volume distributions calculated for each simulation can be used with confidence for risk analysis, contingency planning or emergency response.

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SPREADING OF OIL IN SNOW

A field experiment

by

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Abstract.

A series of experiments have been carried out to study the natural spread of Oseberg crude oil and Marine diesel in snow, both on horizontal and sloping planes. Five experiments, each with 1000 litres of oil, were done for both crude oil and diesel. The release conditions included release under snow and release on top of the snow layer. When released on horizontal planes spreading was more or less circular, and the maximum spreading radius for diesel was 6.5 meters, and less for the crude oil. The oil spreading rate was initially rapid, but decreased to a very slow rate. When a steady state condition was established the oil was distributed in what we have called a primary and a secondary contamination area. The primary area was the fraction of the spill extension with oil partitioned more or less throughout the snow layer, while in the secondary area oil was distributed only under the snow.

INTRODUCTION

Most industrial activities involves risk of accidental pollution. In arctic areas the overall risk might increase due to severe environmental constrains, and an assumed slow recovery of a vulnerable nature, if severely disturbed. In the Norwegian arctic the industrial activity has been limited until now. However, as part of an increasing interest for exploring resources in the Norwegian Arctic Norsk Hydro in cooperation with Petro Arctic and Store Norske Spitsbergen Kullkompani; drilling for hydrocarbons started on shore on Spitsbergen in January 1991. The drilling is called Reindalen 1. Drilling activities is limited to the winter period. Both Norwegian oil companies, and the pollution authorities had limited experience with oil spill contingency in arctic winter situations.

Earlier drillings for hydrocarbons on Spitsbergen have been carried out in summer, en close to the shoreline. The present drilling thus presented a considerable challenge to the operating company Norsk Hydro, in reducing the potential risk to the arctic environment. Considerable efforts was initiated on most aspect related to the environmental aspects of the drilling activities.

This paper presents the main results of experiments with spreading of oil in snow. Snow will be the major substrate for the storage of oil resulting from spills in arctic winter situations. Snow is a porous medium with a retention potential depending on the snow and oil properties. Our experiments were done to give better data for the understanding of how oil distribute in snow after spills, and on how this has to be taken into consideration for the cleanup techniques that are selected. Results from the experiments were also used in parameterization of a computer model based on the process equations developed by Belore and Buist (1988). This part of our study, as well as experiments to determine rates of evaporation, are not treated in this paper.

The first studies on the behavior of oil in snow and ice were carried out by McMinn (1973) with Prudhoe Bay crude oil. These experiments , together with experimental spills with Norman Wells crude oil on freezing water done by Scott and Chatterje (1972) gives data on weathering of oil in snow. Mackay et al. (1974) developed a simple computer model for the fate of oil in snow, based on experimental data from 12 experimental spills. The Balena Bay study (NORCOR 1975), included experiments with Norman Wells crude, to determine sorption and evaporation of oil from snow. Recently Belore and Buist (1988), studied spreading of oil, and evaporation of oil absorbed in snow, and developed process equation for modelling.

Spreading of oil in snow is a complex process. Darcy's equation for flow in porus media is valid for transport of oil into snow (Mackay, 1974). This part of the project which is a study of isothermal spreading of Oseberg crude oil and diesel oil and especially concerning:

- surface spreading
- permeation
- horizontal flow on impermeable layer
- absorption
- drainage

MATERIAL AND METHODS

The experiments were carried out in April–May 1990 near SINTEF's laboratory in Sveagruva on Spitsbergen. Most of the spread studies were carried out in the horizontal ice covered Van Mijenfjord, except for two experiments which were conducted on sloping moraine terrain.

The test oils

Oseberg crude and diesel oil were selected as model oils in the experiment. Despite other drilling operations at Spitsbergen or in the Barent Sea, oil producing sediments have not yet been proved and the properties of the oil from this region are unknown. Correlation of the results from this study with the properties of a crude oil that is eventually found will be necessary. However, the results from the experiments with diesel oil are directly applicable. Diesel oil is stored in large quantities both at the drilling site and other places on Spitsbergen, and is used as fuel in vehicles and in electricity production. Diesel oil spillage along the transportation route is more probable at the present stage, than crude oil spills.

The physical – chemical properties of Oseberg crude and diesel oil are given in Table 1. Anton Paar DMA 35 was used to determine the density. Interfacial tension was determined by use of a KRUSS digital tensiometer KIOT (ring method) and viscosity was measured by a Brookfield DV II viscosimeter.

As this was an isothermal spread study the temperature of the oil varied with the air temperature, between –4.5 and –18°C throughout the experimental period.

Snow properties

The variation in snow properties were minimized as the experimental period was relatively short and the experiments were carried out close to each other. The porosity of the snow varied between 0.4 and 0.5.

Table 1. Physical and chemical properties of the two oil types used in the spreading experiments with oil in snow; i.e. Marine diesel and Oseberg crude oil.

Properties	Diesel	Oseberg crude
Density (g/ml)	0.847	0.849
Surface tension (mN/m)		
air/oil	29	29
oil/seawater	20	21
Pour point (°C)	– 27	– 24
Flash point (°C)	55	46.1
Viscosity (–5°C, cp)	6.2	54

Horizontal flow of oil in snow

The study of the spread of oil on an horizontal impermeable layer was carried out on the ice-covered Van Mijenfjord. A total of eight experiments were done. The spill rate varied between 0.7 and 2 litres/sec. approximately. Table 2 gives a summary of the spread experiments.

The design of these studies was similar to that used by Belore and Buist (1988). Our experimental set-up is illustrated in Figure 1.

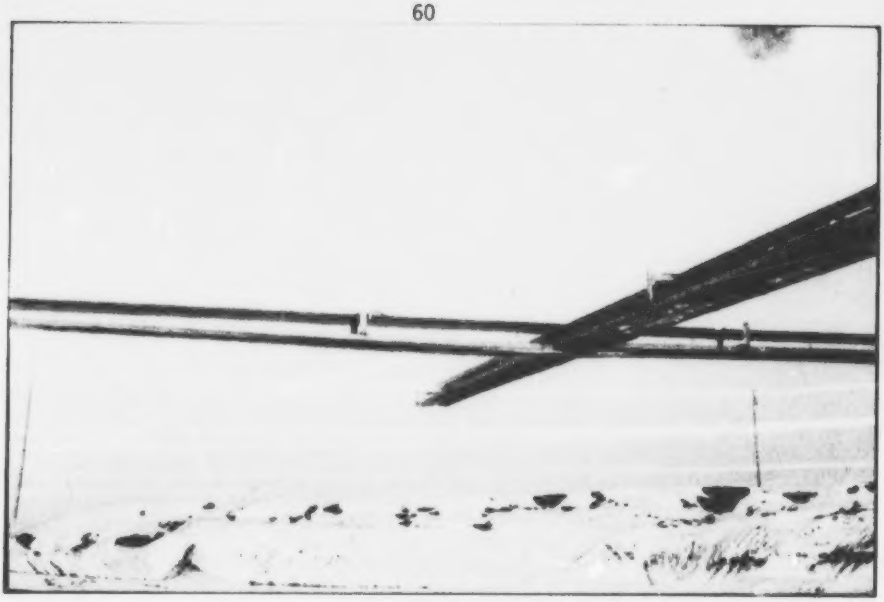

Figure 1. The experimental set-up for the spread studies. Oil was released in the centre of the test area which was 10 x10 metres.

By pumping oil from a reservoir, 1000 litres was released from the centre of the experimental area which was 10 x 10 metre. The spread was monitored from catwalks along the four axes. The experiments were conducted with virgin snow which had a thickness of 60 cm (approx.).

Oil was released in two ways: on the snow surface and under the snow. To study the surface spread, oil was released onto a circular plate on the snow surface. The two types of release conditions are shown in Figure 2.

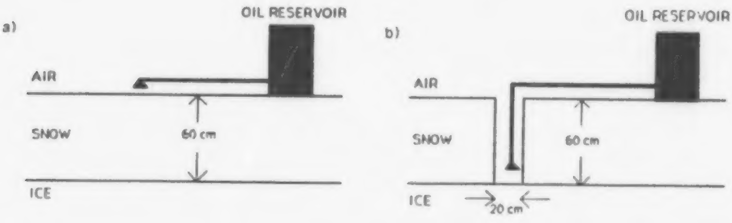

Figure 2. Oil release during the experiment. The oil was released in the centre of the experimental area either a) on snow surface, or b) under snow surface.

Oil spread was monitored in two ways. When oil was released under the snow, spreading was monitored in observation wells that were made before the release of the oil. The distance between the wells was 25 cm. As the oil ceased to spread additional wells were made to allow for additional observations. In the experiments with the release of oil on the top of the snow, oil spread was observed visually until the horizontal visual transport stopped. After this, observation wells were made to study the subsequent in–snow and under–snow spreading.

Table 2. Summary of the experiments with the spread of oil in snow.

Exp. #	Oil type	Release rate (l/sec)	Spill conditions	Plane
C1	Oseberg crude	0.72	Under snow	Horizontal
C2	Oseberg crude	0.74	On snow	Horizontal
C3	Oseberg crude	0.72	On snow	Sloping
C4	Oseberg crude	1.38	Under snow	Horizontal
C5	Oseberg Crude	2.08	On snow	Horizontal
D1	Diesel	0.72	Under snow	Horizontal
D2	Diesel	0.72	On snow	Horizontal
D3	Diesel	0.72	On snow	Sloping
D4	Diesel	2.15	Under snow	Horizontal
D5	Diesel	1.85	On snow	Horizontal

When the spread has stabilized the total contaminated area was located by use of a rotary snow cutter and ploughed in different directions. The oil concentrations were monitored by samples taken from different levels in the snow and from different distances from the centre.

Sloping terrain

Two experiments were carried out in sloping terrain (Table 2; Exp C3 and D3). In these studies crude oil and diesel oil were pumped from a reservoir to the snow. The spread on snow was studied. In these two experiments oil was spilled in moraine terrain. The snow depth varied from 30 cm to 1.5 metres. The slope of the terrain was approximately 30 degrees.

RESULTS AND DISCUSSION

Horizontal spread of oil under snow

Experiments C1, C4 and D1 and D4 studied the spread of oil under snow. Oil was released 10 cm above the ground into a release hole by pumping. When pumping the oil, the driving force was the hydrostatic head in the bore hole. The spread was more or less radial and followed an exponential function.

Table 3 lists the results from the spread studies. As can be seen, the oil is distributed in two areas: a primary and a secondary spread area. In the primary spread area the thickness of the contaminated snow is nearly the same as snow thickness. The extent of this area is defined by the surface spread. At the edges it decreases to the level of the secondary spread area. Oil concentrations in this area depend on the capacity of the snow to absorb the oil. The secondary spread area is defined by the spill volume, oil and snow properties and the permeability of the ground. The thickness of the oil layer on the ground varied in this area from 2 cm to 10 cm. The difference between what we have called the primary and secondary spread areas is illustrated in Figure 3.

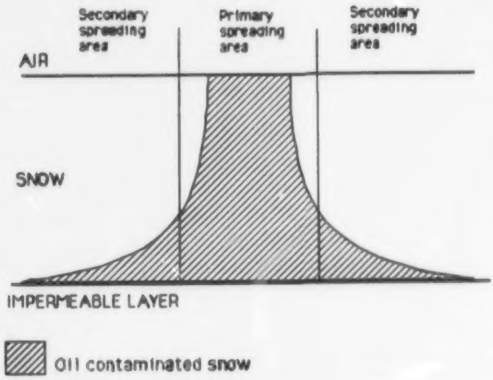

Figure 3. Primary and secondary spreading area.

Figures 4 and 5 illustrate the spreading of crude oil in Exp. C1 and C4. The spill rates were 0.72 and 1.38 l/sec respectively. Despite the higher spill rate in Exp. C4 the polluted area immediately after release was smaller than in Exp.C1. This is probably an effect of the differences in oil viscosity due to temperature differences when carrying out Exp. C1 and C4 (Table 3). When the spreading had stabilized the contaminated area is approximately the same. When the oil head disappears the oil saturated region near the source will drain. Drainage was a relatively rapid process just after termination but decreases with time and oil concentrations.

Diesel oil spreads faster than crude oil due to lower viscosity. Figures 6 and 7 show the spread of diesel oil. The spill rate was 2.14 l/sec. In these experiments the most pronounced difference between spreading of crude and diesel oil was the total contaminated area under the snow when oil had stabilized. As can be seen from Table 3, diesel oil contaminates approximately twice the area of crude oil. The great difference between contaminated area immediately after release and a few days later indicate the very slow spread of oil.

Snow samples near the centre showed that residual oil saturation near the ground was 25 % for crude oil and 15 % for diesel oil (approx.). In addition to oil properties, the oil concentrations was a function of snow properties and distance from the ground.

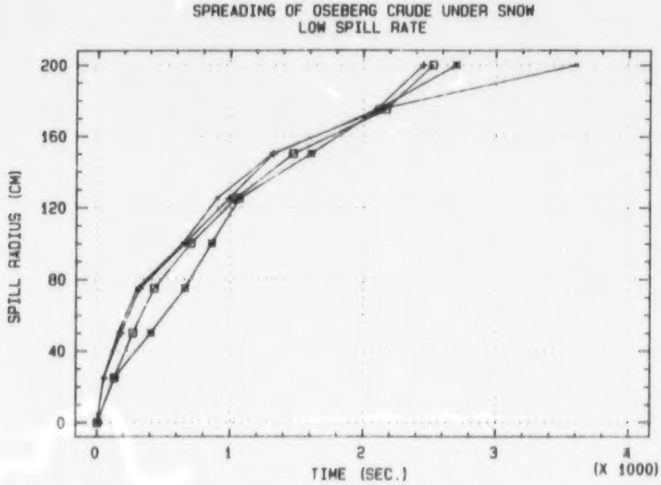

Figure 4. Spreading of crude oil released under snow, Exp.C1. Low spill rate (i.e. 0.72 l/sec.)

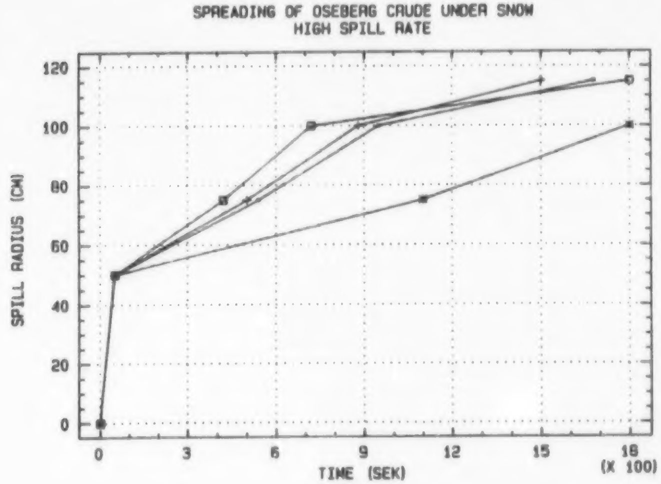

Figure 5. The spread of crude oil released under snow, Exp C4. High spill rate (i.e. 1.38 l/sec.).

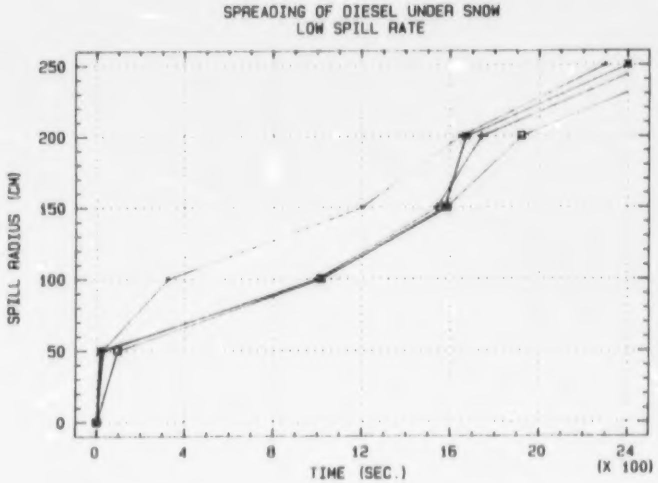

Figure 6. The spread of diesel released under snow, Exp D1.
Low spill rate (i.e. 0.72 l/sec.).

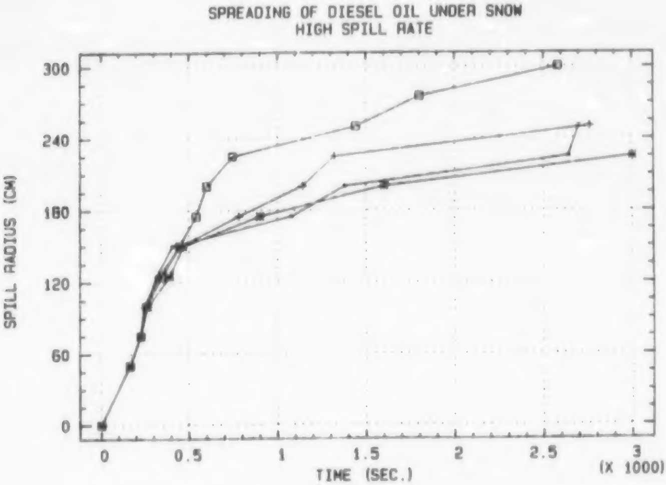

Figure 7. Spreading of diesel released under snow, Exp. D4.
High spill rate (i.e. 2.15 l/sec.).

Spreading of oil with release on snow surface.

Experiments C2, C3, C5, D2, D3 and D5 studied the spread after surface release of oil. The spread of oil on snow is strongly dependent on the snow surface properties and the spill rate. Within each test area there are natural variations in snow topography and porosity. This made it difficult to illustrate the flow of oil on the snow. Just after release oil spreads quickly but once penetration has started, further surface spreading was limited. In oil-saturated snow the penetration rate increases relative to unpolluted snow, where surface tension reduces the flow (Mackay 1974).

Figures 8 and 9 illustrate the surface spread of crude oil in Exp. C2 and C5, along the four axes. The spill rate was 0.74 and 2.08 l/sec. respectively. As can be seen, surface spread was limited and non-radial due to uneven snow surface.

In experiments D2 and D5 diesel oil was released on the snow surface. The spread is presented in Figures 10 and 11. The low spill (0.72 l/sec.) rate gave a maximum surface extent of about 85 cm while the increasing spill rate to 1.85 l/sec gave a maximum radial spread of about 3 metres. The final spread of oil under snow in these experiments was 60 and 118 m^2 respectively.
The spread on the surface depends on the spill rate. As in the studies with the spread of oil under snow, the final total contaminated area depends on oil properties in addition to the snow properties.

Spatial distribution of oil after spreading

The spill profiles of the oil in the snow differ somewhat between the experiments. In experiments with a slow release rate, the primary contamination area tends to be smaller than in the experiment with a low release rate. Figures 12-15 illustrate the distribution of crude oil (in cm) at the termination of Experiments C1 and C5; and D1 and D5.

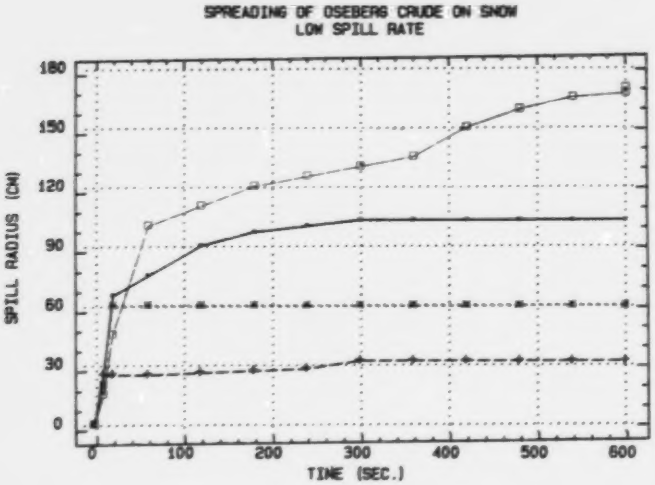

Figure 8. The spread of crude oil released on the snow surface, Exp C2. Low spill rate (i.e. 0.74 l/sec.).

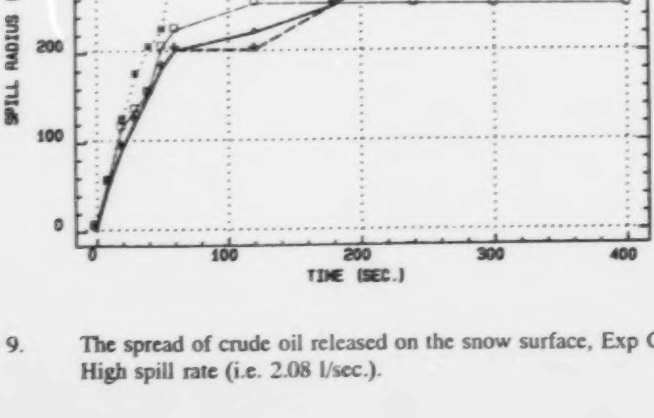

Figure 9. The spread of crude oil released on the snow surface, Exp C5. High spill rate (i.e. 2.08 l/sec.).

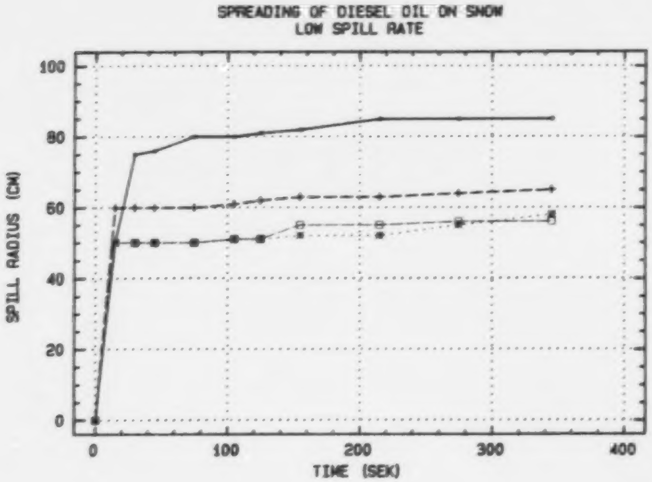

Figure 10. The spread of diesel oil released on the snow surface, Exp D2. Low spill rate (i.e. 0.72 l/sec.).

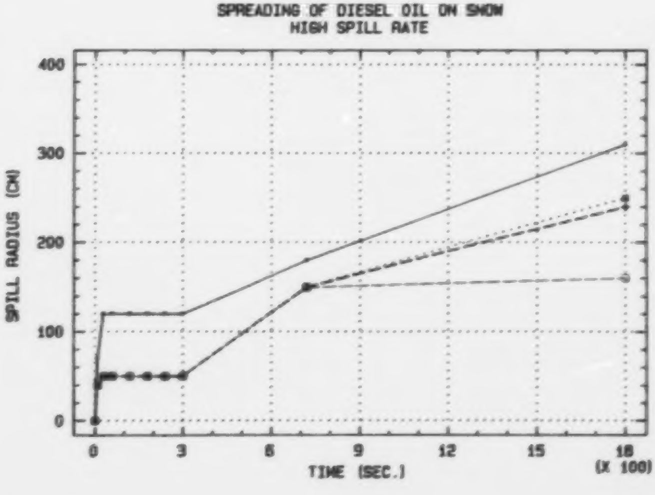

Figure 11. The spread of diesel oil released on the snow surface, Exp D5. High spill rate (i.e. 1.85 l/sec.).

Table 3. Results from the spread studies.

	Exp. no.	Temp. (°C)	Visc. (cp)	Spill rate (1/sec)	Perm. m^2	Area * m^2	Area ** m^2	Prim. area *** m^2
Release under snow	C1	-4.5	35	0.72	$1.6 \cdot 10^{-7}$	12	28	3.5
	C4	-9.4	250	1.38	$1.6 \cdot 10^{-7}$	4	33	4
	D1	-17.7	10	0.72	$2.2 \cdot 10^{-6}$	16	72	0.6
	D4	-9.4	7	2.15	$1.6 \cdot 10^{-6}$	19	64	3.2
Release on snow surface	C2	-4.5	35	0.74		3	23	5
	C5	-9.4	250	2.08		27	14	3.8
	D2	-13	7.5	0.72		1.5	60	1.5
	D5	-9.4	7	1.85		19	118	19

* Contaminated area just after release

** Contaminated area some days after release, when spreading has stabilized

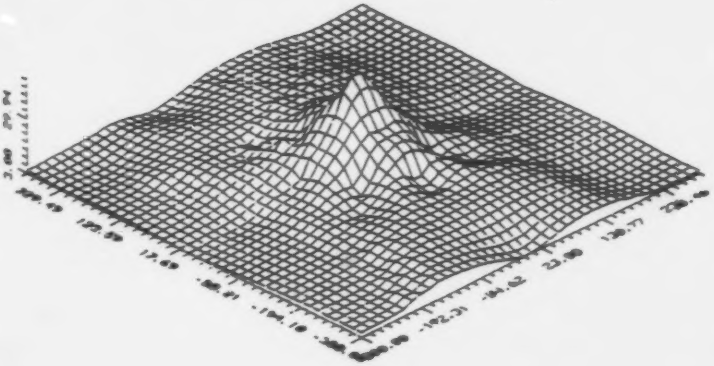

Figure 12. Spatial distribution of crude oil from Exp. C1 (i.e. x-and y-axis represent the total horizontal spread of oil and the z-axis gives the vertical distribution of oil in the snow).

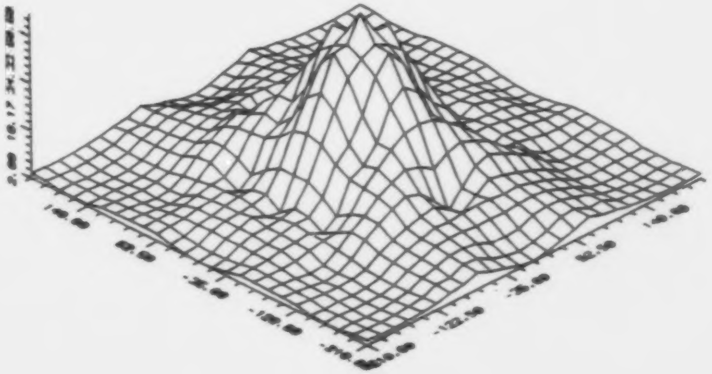

Figure 13. Spatial distribution of crude oil from Exp. C5 (i.e. x-and y-axes represent the total horizontal spread of oil and the z axis gives the vertical distribution of oil in the snow).

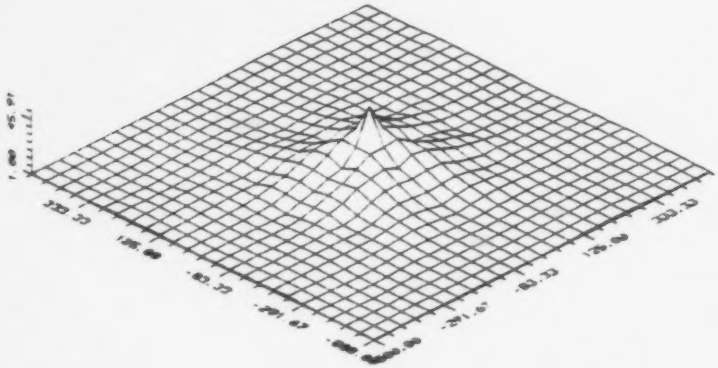

Figure 14. Spatial distribution of diesel oil from Exp. D1 (i.e. x- and y-axes represent the total horizontal spread of oil and the z-axis gives the vertical distribution of oil in the snow).

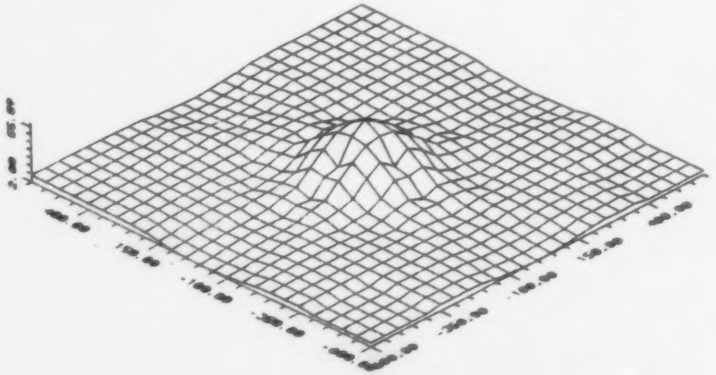

Figure 15. Spatial distribution of diesel oil from Exp. D5 (i.e. x-and y-axis represent the total horizontal spread of oil and the z-axis gives the vertical distribution of oil in the snow).

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DEVELOPMENT OF A PORTABLE FIELD KIT FOR MEASURING PROPERTIES OF SPILLED OILS

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ABSTRACT

A portable kit is being developed specifically for measuring oil properties at the spill site. The kit is capable of measuring density, viscosity, flash point, water content and the chemical dispersibility of oil. This paper describes the evaluation and selection of the methods and components of the kit.

INTRODUCTION

The effectiveness of any countermeasure technique is, to a certain degree, dependent upon the physical characteristics of the spilled oil. Once oil is released into the environment, its properties are in a dynamic state due to weathering. This means that countermeasures must be adapted to deal with the changing characteristics of the oil. For example, the opportunity to use dispersants effectively is usually limited to the early stages of the spill before significant evaporation and emulsification have occurred. As well, the efficiencies of most mechanical recovery devices are limited by the rheological properties of the recovered material (Exxon, 1990). A skimmer that works well one day may become ineffective the next day because the viscosity of oil has increased beyond the capability of the equipment.

On-scene decision-makers must quickly assess the situation and then decide where to deploy the resources available. Usually the performance limits of equipment are known but not the properties of the spilled oil; at best, the properties can only be estimated. Sending samples away to be analyzed would be neither time effective nor practical. Thus, the utility of field analysis becomes evident.

The objective of this project was to develop a portable analytical kit which can be taken to the spill site and used to obtain rapid and reliable measurements of crucial oil properties. On-scene personnel can determine and monitor the properties of the oil. This information could then be readily incorporated into the operational decision-making process.

REQUIREMENTS OF THE KIT

The kit will measure the following properties:

- Density

  Oil density indicates the possibility of the oil sinking or being overwashed (Buist and Potter, 1987; Wilson et al., 1986).
- Viscosity

  Viscosity is a measure of fluidity and is normally the limiting factor for mechanical skimming and pumping equipment. Oil viscosity is also a major determinant of spreading.
- Flash point

  Flash point is a measurement of flammability, and is a safety factor that can influence operational decision-making.
- Water content

  The quantity of water in the sample indicates the degree of emulsification.
- Dispersibility

  A dispersibility test will show if the oil can potentially be dispersed.

In order for specific equipment and methods to be considered as part of the kit, each had to meet the criteria as described below:

- Equipment must be compatible with the limited space and weight requirements of a self-contained portable kit. The complete kit should be easily carried by no more than two persons, and can be shipped by all common forms of transportation;
- Testing can safely be performed under the demanding operational conditions expected;
- Equipment should be relatively simple to operate with little prior training and results easy to interpret;
- Results are to be within specified limits of accuracy and repeatability. Test procedures should be based upon generally accepted and standardized analytical methods;
- Definitive results are produced within hours of receipt of a sample.

EVALUATION OF EQUIPMENT AND METHODS

An extensive literature search of current methods and instruments used to analyze petroleum in the laboratory and in the field was carried out. Manufacturers were contacted and specific details regarding the equipment were obtained. Methods and apparatus that met the set criteria were selected to undergo physical testing. Any modifications to the equipment and procedures which were necessary to make the tests field-portable were instituted at this time. Laboratory tests were conducted using a variety of oils and water-in-oil emulsions. Testing was conducted under conditions which simulated the operating conditions expected at a remote spill site or on a ship at sea. The sensitivity of tests to movement and to temperature were examined. Results obtained using the field procedures were then compared with data from standard laboratory analyses.

EVALUATION OF EXISTING FIELD TESTS

Fina Oil Spill Test Kit

The Fina oil spill test kit was developed in the late 1970's by Labofina S.A.(Belgium) for the Dutch authorities Rijkswaterstaat. At the present time, it is the only portable kit available for measuring the properties of spilled oil. A Fina kit was purchased and thoroughly tested. The following is a brief summary of the evaluation.

Many of ~~the~~ test methods used in this kit are based upon empirical estimation and not upon generally accepted analytical methods. Measurements therefore require subjective interpretation by the operator. Consequently, the precision and accuracy depend upon the operator, the working environment, and the physical characteristics of the sample. Several tests involve difficult, time-consuming manipulations, and require relatively large amounts of oil. Little or no provision is made for cleaning the equipment; thus, performing repeat measurements is difficult. The kit and consumable supplies used for the tests are not readily available in North America.

Although the Fina kit can measure 11 properties, the methods used do not generally follow standardized procedures. Since the development of the Fina kit, there have been significant advances in analytical instrumentation. Modern instruments are more accurate, user friendly, and conform to standardized methods. Many of these instruments can be made field portable.

Field Dispersant Effectiveness Tests

A previous study by Ross (Ross, 1988) examined four different field tests for determining dispersant effectiveness (Pelletier Screen Test, Fina Spill Test Kit, Mackay Simple Field Test, and EPA's Field Dispersant Effectiveness Test). All tests were designed to provide quick, qualitative results. The EPA's Field Dispersant Effectiveness Test (FDET) is commercially available (Sunshine Technology Corporation - West Hartford, Connecticut) and the Fina Test is part of the Fina Oil Spill Test Kit. The other test kits must be assembled by the user. Ross found that the portable tests, although simple to perform, had deficiencies. The most serious problem was the lack of correlation between the results of the field tests and accepted laboratory tests. Ross developed a test (the S.L.Ross Field Test) which overcame most of the deficiencies of the earlier field tests. It provided quantitative results of effectiveness which correlated with the Warren Spring Laboratory Rotating Flask Test.

METHODS AND EQUIPMENT SELECTED FOR KIT

Procedures were chosen for the five physical measurements, as well as for collecting and preparing oil samples. For most of the tests, numerous methods and apparatus were evaluated, this work is not described here.

Sample Collection and Preparation

Equipment is provided in the kit to collect oil samples from both an oiled beach and from the water surface. Beach samples are collected in a container using a scoop. A Teflon/polypropylene net on a telescopic extension pole is used to gather oil floating on the water surface.

Debris in the sample, such as beach material and flora, could potentially damage the more sensitive instruments included in the kit, as well as affect the measurements. It is therefore important to remove any interfering material from the samples. This must be done in such a way as not to alter the properties of the oil. A self-contained filter press is provided with the kit (Fann Model MB Filter Press, Baroid Testing Equipment - Houston, Texas). This filter press is extremely rugged and portable. It is designed to be used by the drilling industry for on-site filtration tests of drilling mud. Carbon dioxide from small, disposable gas cartridges is used to provide pressure which forces the sample through a filter medium. A specially designed polyester mesh filter of 105 micron size is provided with the kit.

Density

An Anton Paar DMA35 density meter (Anton Paar K.G. - Austria) is used to measure density. This hand-held instrument is battery-powered and provides digital readings in grams per milliliter (± 0.001 g/mL) within seconds. It has an operational temperature range of 0 to 40°C and requires only 2 mL of sample. The density meter uses the mechanical oscillator technique, which determines density from the change in vibrational frequency. The procedure is similar to ASTM D4052-86 "Standard Test Method for Density and Relative Density of Liquids by Digital Density Meter."

Viscosity

Viscosity measurements are performed using a Bohlin Visco 88 BV viscometer (Bohlin Reologi Inc. - Sweden). This variable speed rotational viscometer is fully portable and battery-powered. It can be operated as a hand-held instrument and provides a direct reading of viscosity in Pascal-seconds (1 Pascal-second = 1000 centipoise). Samples with viscosities from 0.006 to 350 Pa-s (6 to 350,000 cP) can be measured.

The Visco 88 provides many features that are normally found only in larger, more expensive laboratory viscometers, and it is the only rotational viscometer that is battery operated. The viscometer's built-in software gives it the capability to generate different types of rheological data. These can be used to characterize the non-Newtonian flow behaviour of samples, such as water-in-oil mousse. Direct readings from the instrument can be used to generate rheological flow curves (shear rate versus shear stress, and viscosity versus shear rate). The flow curves can then be used to calculate yield points and apparent viscosities. The viscometer can interface with a computer to increase the operating and data analysis capabilities.

Water Content

Determining the water content of a stable mousse, even under laboratory conditions, can be extremely difficult. Evaluation of existing methods which could be adapted for field use showed that only the volumetric Karl Fischer titration technique would analyze viscous emulsions reliably and consistently. The instrument that was chosen was a Metrohm 701 Karl Fischer Titrator (Metrohm Limited - Switzerland). This automated system can measure water content of any substance from 0 to 100%. Analysis takes only a few minutes and repeat measurements are easily performed. The instrument is self-cleaning and will display the calculated water content. The instrument has been equipped with a DC/AC inverter, thus allowing it to operate using 120 volt AC or a gel cell (12 volt car battery).

The test procedure is analogous to the protocols for API MPMS (chapter 10.7), ASTM D4377-88 and IP 356/87 - "Standard Test Method for Water in Crude Oils (Karl Fischer) Titration." A 100 microliter sample is injected into the titration vessel containing a solvent mixture (1:1:2, methanol:chloroform:toluene) which dissolves the emulsion. The free water is then automatically titrated to an electrometric end point with Karl Fischer reagent. The water content is displayed on the screen as a weight percent value.

Flash Point

The Setaflash Model 13740 (Stanhope/Seta - England) is a portable unit powered either by a 120 volt AC source or a 12 volt battery. It has a measuring range of 0 to 100°C. The test will be conducted as a flash/no flash procedure at two selected temperatures: the prevailing environmental temperature and 60°C. The procedure is based on ASTM D3828-87 and IP 303/80 "Standard

Test Methods for Flash Point By Setaflash Closed Tester".

Dispersibility

The use of dispersants remains an attractive countermeasure option for dealing with large oil spills. At this time there are a variety of tests for measuring dispersant effectiveness. Unfortunately, different tests can yield very different values. It should be recognized that no test, not even an elaborate laboratory test, can fully simulate oceanographic conditions. Nevertheless, many recent advances have been made in understanding the variables that affect dispersant effectiveness. After reviewing the existing field tests (Pelletier Screen Test, Fina Spill Test Kit, Mackay Simple Field Test, EPA's Field Dispersant Effectiveness Test, and S.L. Ross Field Test), it was concluded that it was possible to draw upon all findings and develop a procedure that would avoid most of the artifacts and deficiencies of existing tests. This portable test will allow on-scene personnel to examine the relative effectiveness of a dispersant on an actual sample of the spilled oil using indigenous water and prevailing environmental temperatures.

The test selected was designed in such a way as to allow the operator to make a quick qualitative observation of dispersant effectiveness, and to obtain a quantitative value of effectiveness. The difficulties associated with using visual methods were pointed out by Ross (Ross, 1988) in his evaluation of field dispersant effectiveness tests. A major problem is that the colour of the oil affects the amount of oil perceived to be dispersed. If two oils of different colours were equally dispersed, the darker oil appears to be more dispersed. Therefore, assigning any kind of numerical value to effectiveness based on the appearance of the water containing the dispersed oil can be erroneous, if calibration standards are not prepared for comparison. These standards must use the same oil, water and dispersant that will be used during the sample test. A visual inspection will show, at least qualitatively, if the dispersant has had any effect. This can be done by comparing the results from a dispersant-treated oil against a non-treated oil. The non-treated oil will show the oil's natural dispersibility and thus act as a control. In order to obtain a valid measure of effectiveness, the amount of oil dispersed into the water must be analyzed using appropriate techniques.

During the development of this test, numerous methods were examined. Different vessels were tested and different modes of mixing energy were studied. The test method described here was chosen because it can be performed easily and rapidly, the results are relatively insensitive to minor variations in mixing energy due to the human operator, and the values are repeatable and comparable to laboratory effectiveness tests. The test takes into account factors not considered by the previous field tests. Recent findings (Daling, 1988; Fingas et al., 1989; Fingas and Kolakowski, 1990; Nes, 1984) have shown the importance of certain variables on dispersant effectiveness testing. These variables are: the water-to-oil ratio; the length of settling time between the cessation of mixing energy and the withdrawal of a water sample; the extent to which the oil naturally disperses; and the manner in which the standards are prepared. Each of these factors has been shown to have a significant effect upon dispersibility. It has been demonstrated that when the protocols of various existing laboratory tests are adjusted in such a way that these conditions are taken into account, the different tests yield comparable results (Fingas et al., 1989). None of the previous field tests account for these recent findings in their protocols.

The spill kit procedure entails adding 200 μL of oil (premixed with dispersant at a dispersant-to-oil ratio of 1:25) to 240 mL of seawater contained in a 250 mL Teflon separatory funnel. The funnel is hand-rotated at 30 rpm for two minutes and then allowed to settle for 30 minutes. A 30 mL water sample is drained into a 125 mL separatory funnel where it is extracted with 15 mL of solvent. The same procedure is used for determining natural dispersibility, except that dispersant is not added. A set of standards is made up by adding 5 μL, 15 μL, and 25 μL of oil (premixed with dispersant) to 30 mL of water. The entire volume of each standard is then extracted using 15 mL of solvent. The standards represent 20%, 60% and 100% dispersion respectively. Dichloromethane is the solvent that is presently specified, but the use of other solvents is being examined.

An estimate of the amount of oil that has been dispersed can be obtained by comparing the colour of the solvent from the test runs (both the natural and chemical dispersibility) to the colours of the standard solvents. An accurate determination of effectiveness can be made spectrophotometrically. The kit contains a hand-held, battery-powered Mini Spectronic 20 spectrophotometer (Milton-Roy Ltd. - Rochester, New York). The operator will use scaled graph paper to plot the transmittance values of the standards versus percent oil dispersed in order to obtain a calibration curve. The percentage of the test oil dispersed can be read directly from the graph.

RESULTS

The instruments and standard methods used for the laboratory analyses are listed in Table I. Table II illustrates that the results obtained for density, viscosity, flash point, and water content using the field kit instruments are in good agreement with measurements from standard laboratory methods. It can also be seen from Figure 1 that the Bohlin viscometer provides an accurate rheological characterization of a water-in-oil mousse that exhibits non-Newtonian flow behaviour.

Table I: Laboratory Equipment and Methods

Test	Method
Density - Anton Paar DMA 45 digital density meter	ASTM D4052 - 86
Viscosity - Haake RV20 rotational viscometer	DIN 53018
Flash Point - Pensky-Martens Closed Tester	ASTM D93 - 85
Water Content - Photovolt Coulometric Karl Fischer	ASTM D1533 - 88 Method B

Table II: Comparison of Test Kit Results and Laboratory Results

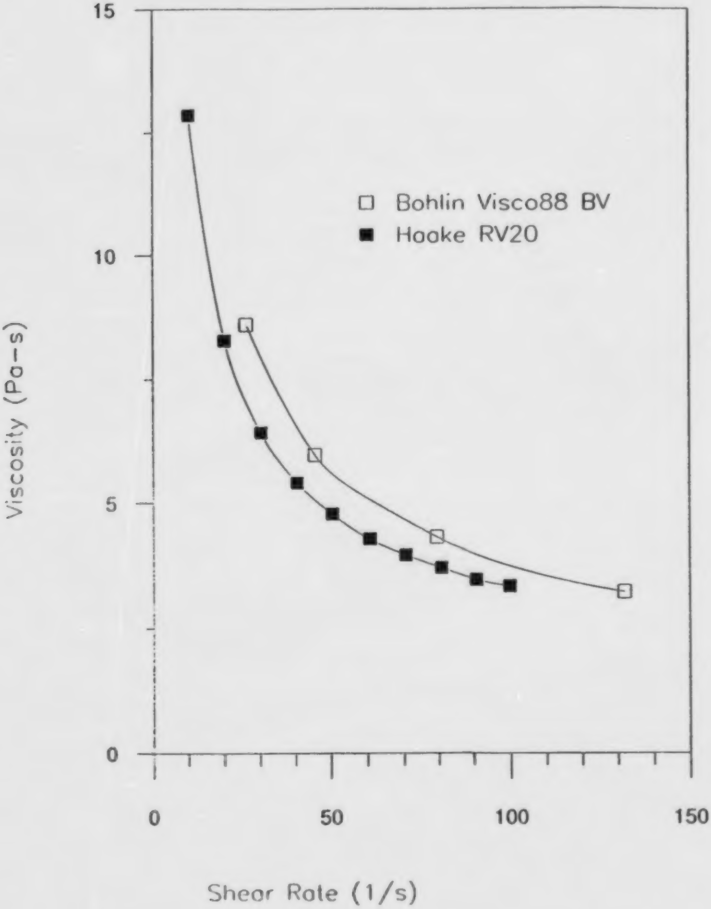
Test	Sample	Test Kit Result	Lab Result	Absolute Error
Density (g/ml)	ASMB* Crude	0.840(15°C)	0.8458(15°C)	0.0058
		0.847(0°C)	0.8514(0°C)	0.0044
	Norman Wells Crude	0.866(15°C)	0.8674(15°C)	0.0014
	Endicott Crude	0.915(15°C)	0.9154(15°C)	0.0004
	Emulsion	1.003(15°C)	1.0010(15°C)	0.0020
		1.005(0°C)	1.0041(0°C).	0.0009
Viscosity (Pa-s)	Standard	1.049	1.0007	0.0483
Flash Point (°C)	Jet Fuel A1	44	42***	2
	ASMB	6	7***	1
	Mousse Mix Oil**	72	71	1
Water Content (%)	Emulsion	69.31	69.00	0.31

* Alberta Sweet Mix Blend Crude Oil.

** this oil is a mixture of 50% Bunker C and 50% Alberta Sweet Mix Blend. The oil has been artificially weathered by air stripping; 7.7% by weight of the oil was evaporated off.

*** Data taken from Bobra and Callaghan (Bobra and Callaghan, 1990).

Figure 1: Viscosity versus Shear Rate Graph
Water-in-Oil Emulsion at 15 degrees Celcius



The dispersibility values for four oils as determined by the Portable Field Kit Test are presented in Table III, along with results obtained from the Warren Spring Laboratory Rotating Flask Test and the Swirling Flask Test. Procedures for the WSL Test and the Swirling Flask Test were taken from Martinelli (Martinelli, 1984) and Fingas et al. (Fingas et al., 1989). Tests were conducted at room temperature using oil pre-mixed with Corexit 9527 at a dispersant-to-oil ratio of 1:25. For all tests, an oil-to-water ratio of 1:1200 was used and the settling period was 30 minutes. All three tests rank the oils in the same order of dispersibility; Bunker C was the least dispersed and Alberta Sweet Mix Blend was the most dispersed. The results obtained using the Portable Field Kit Test are comparable with the other tests; the effectiveness values from the Portable Field Kit are in-between those of the Swirling Flask Test and those of the WSL Test.

Table III: Dispersibility Results

Apparatus	Oil	Dispersibility %	No. of Data Points
WSL* Rotating Flask Test	Alberta Sweet Mix Blend	57% ± 10%	9
	Norman Wells	54% ± 4%	9
	Endicott	38% ± 10%	9
	Bunker C	7% ± 5%	9
Portable Field Kit Test**	Alberta Sweet Mix Blend	53% ± 12%	52
	Norman Wells	31% ± 10%	11
	Endicott	8% ± 3%	13
	Bunker C	3% ± 3%	5
Swirling Flask Test	Alberta Sweet Mix Blend	20% ± 4%	12
	Norman Wells	20% ± 2%	8
	Endicott	3% ± 3%	8
	Bunker C	1% ± 1%	8

* Warren Spring Laboratory

** data include runs where the rpm was varied slightly and the size of the separatory funnel was altered.

NOTE: All dispersibility results were measured after a 30 minute settling time. The dispersibility results are written as the arithmetic mean plus/minus the standard deviation.

SUMMARY

Individual test components of a portable field kit have been selected and have undergone testing in the laboratory under simulated field conditions. The test methods were selected on the basis of portability, simplicity, safety, ruggedness, and reliability. A step-by-step manual is being compiled which provides detailed operation and maintenance procedures. A storage/transportation container is being designed that will hold all instruments and peripheral equipment. Besides protecting the kit during transportation, the container will also serve as a "lab station" which can easily be secured for aboard-ship operation where the tests can readily be performed.

Although refinements to the procedures are still being performed, the equipment is presently in a ready-to-go state. Should a spill-of-opportunity occur, the kit and an operator can be provided. The performance of the kit under field conditions will be assessed and appropriate improvements made.

ACKNOWLEDGEMENTS

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PHYSICAL AND CHEMICAL STUDIES ON OIL SPILL DISPERSANTS: THE EFFECT OF ENERGY

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INTRODUCTION

Energy has been ascribed as the principle reason for the varying results of dispersant effectiveness results in the field and in the laboratory. Difficulties in varying or measuring this energy have left the variation of dispersion and energy largely unstudied. Energy is a difficult topic.[1] Descriptions of what is meant by relevant energy to oil dispersion varies. One description of energy is that it is a relative measure of the wavelength and amount of turbulence in the near surface. [2] Another definition is that of steepness of waves and their periods. [3] Several discussions on the relationship between dispersion and energy have taken place, but little experimental work has been published.[4-7] Fundamental literature on surfactants also does not propose energy relationships. [8,9]

Many different types of dispersant test procedures and apparatus are described in the literature. One estimate places this at 50 different tests or procedures.[10-15] Little work has been done on determining the reason for the poor correlation between test results. Most of the investigators cite energy as being the most significant factor. The general conclusion has been that the differences in energy levels and the way these have been applied to the oil/water mixture result in effectiveness values that are unique. Usually investigators followed the specified test procedure when using an apparatus and did not vary any of the conditions.

EFFECT OF OIL-TO-WATER RATIO AND SETTLING TIME

A previous study by Environment Canada found that a significant portion of the variance of dispersant effectiveness among the various apparatus was due to differing settling times and differing oil-to-water ratios.[16] Energy could be compensated for by doing a blank run in the more energetic apparatus and correcting the chemically-dispersed run by this amount. This was based on the assumption that a similar mechanism prevails between chemical or natural dispersion. It should be noted that the noise level is so great in many of the more energetic apparatus that any correction value within a factor of two could give an appropriate result.

The first two variables studied are important to laboratory dispersant tests, the oil-to-water ratio and the settling time, that time between the taking of the sample for analysis and the time that the energy is no longer applied to the apparatus. Increased settling time allows large, unstable oil droplets to rise to the surface before the sample is taken and thus reduces the effectiveness values to represent only the stable dispersions.[16] The oil-to-water ratio varies in the various test protocol. The effect of changing the oil-to-water ratio in some of the apparatus is large and results in a peak at an oil-to-water ratio of 1:500. For two apparatus and for the different oil-dispersant combinations, the overall effect is the same. The effectiveness drops down at ratios below 1:200 and very much at ratios as low as 1:20. The maximum effectiveness is seen at ratios around 1:500 and from 1:1000 becomes relatively stable up to 1:1,000,000. It is suggested that this variation is the result of different mechanisms of dispersant action.[16] At low oil-to-water ratios, there is a large amount of surfactant present and this surfactant interacts with itself forming micelles rather than interacting with the oil. At low ratios, there are sufficient numbers of micelles to solubilize portions of the oil. At high oil-to-water ratios the primary interaction between oil and surfactant is the formation of stabilized droplets. At ratios close to 1:500, both mechanisms come into play and apparent dispersion is increased. The effect of settling time is an important factor in the operating protocol of the various effectiveness experiments. The effect can be as much as one order of magnitude to the apparent dispersion amount.

Although settling time and oil-to-water ratio are shown to be very important in terms of correlating laboratory data, the role of energy has not been fully understood.

EXPERIMENTAL

Several rounds of experiments were conducted to determine the effect of varying energy. Several oils were used in these tests. Table 1 lists these oils and gives their basic physical properties. The dispersants used include the Exxon products Corexit 9527 (abbreviated C9527 in some tables in this paper) and Corexit CRX-8 (abbreviated CRX-8), the Dasic Chemicals Product, Dasic Slickgone LTS (abbreviated Dasic) and the British Petroleum product, Enersperse 700 (abbreviated EN 700). All runs where dispersant was used, were performed with dispersant already mixed in the oil at a ratio of 1 to 25 by volume. This practice was adopted to achieve more repeatable results as determined in earlier experiments where both premixed and drop-wise addition were used.[13] Saltwater was prepared with sodium chloride to 33 oo/o or degrees salinity. All tests were done at a temperature of 20°C. Apparatus, oil and water were left at these temperatures for at least 20 minutes before the beginning of each test to ensure thermal equilibrium. All tests were done in thermally-controlled chambers.

TABLE 1 **TEST OIL PROPERTIES**

OIL	DESCRIPTION	KINEMATIC VISCOSITY *(mm /s AT 15 C)*	DENSITY *(g/mL At 15 C)*
ASMB	ALBERTA SWEET MIXED BLEND	8	0.84
ARABIAN LIGHT	LESSER VISCOSITY ARAB BLEND	40	0.87
BUNKER C LIGHT	LESSER VISCOSITY BUNKER C	200	0.93
NORMAN WELLS	NORTHERN CANADIAN CRUDE	7	0.83
NORTH SLOPE	ALASKAN BEAUFORT CRUDE	55	0.88

The standard swirling flask apparatus was used to study the effect of small changes in energy. The swirling flask apparatus uses a 125 mL Erlenmeyer flask with a standard laboratory shaker to induce a swirling motion to the contents. Procedures for this device are detailed in the literature.[17] For the tests here, the rotational speed was varied from 50 to 450 rpm. Another test was developed using a 2 L Erlenmeyer flask. This flask was operated in a very similar manner to the swirling flask. The oil-to-water ratio was fixed at 1:20,000 and the shaking rotation varied from 50 to 200 rpm to study the effect of energy variation.

The labofina test employs a 250 mL separatory funnel which is rotated at 33 rpm.[18] The apparatus was operated with an oil-to-water ratio of 1:1000 to 1:30,000 and samples were taken after a settling time of 10 minutes. Oil-to-water ratio was varied in this apparatus to study the effect of natural dispersion.

A blender (standard Waring laboratory unit) was used to conduct some of the oil-to-water ratio tests. The volume of water used was 1 L. This apparatus was used primarily to confirm results in other apparatus.

A new apparatus was developed to measure the effects of high energy levels. This apparatus, dubbed "Round High Energy Test", consisted of a cylindrical vessel of dimensions 29 cm., diameter, and 30 cm. height. During operation the vessel is covered. Either 4.8 or 5.4 L of water were used in this apparatus and sufficient oil to yield an oil-to-water ratio of 1:20,000. This is the value found to be the ratio at which natural dispersion no longer increases with increasing oil-to-water ratio.

Another new apparatus, called simply "the high energy test" in our laboratories, was developed to measure dispersion at very high energy levels. This vessel is square of dimensions 30 cm. on all sides. The effect of the corners is to create high levels of turbulence. The volume of oil and water were again the same as in the above device. In both apparatus, the mixing time is 20 minutes and the settling time is 10 minutes before samples are taken. The mixing energy is supplied by a Brunswick shaker consisting of a moving table. This shaker is capable of rotational speed variations from 50 to 450 with relatively good repeatability. The revolutions meter on the shaker is calibrated periodically with a tachometer to ensure accuracy. A pipette is used to remove a 30 mL sample from the apparatus after the settling time.

Analysis for all four apparatus is performed by taking a sample of water from the test vessel after the run is complete, extracting the water with a solvent and measuring the absorbance at three visible wavelengths (370, 340, and 400), and then assigning effectiveness on the basis of a calibration curve. Calibration curves are prepared in a manner similar to the actual runs. Water is used in these calibration runs to ensure that extraction efficiency is compensated for and to compensate for the coloration addition of small water droplets.

STUDY OF OPTIMUM OIL-TO-WATER RATIOS FOR NATURAL DISPERSION

A study of the effect of oil-to-water ratio on amount of oil naturally-dispersed in the water was conducted using 2 different experimental apparatus and procedures. This was done to ensure that the optimal ratio was used for the high energy tests. The first apparatus used was that of the Labofina, as described in the experimental section above. The apparatus was operated as described and the amount of oil added was adjusted to vary the ratio between 1:1000 and 1:30:000. The results of 164 separate experiments are shown in Figure 1. It can be seen that the amount of oil naturally dispersed increases constantly up to a ratio of about 1:20,000 and then appears to stay relatively constant. Data above a ratio of 1:30,000 are hard to obtain because this is the limit of relatively accurate colorimetric oil-in-water measurements and also because the noise level of measurement rises to a high level as a result of the small amount of oil in the apparatus.

A separate series of experiments was performed to verify these results. These were performed in the blender apparatus as described in the experimental section above. Results from these experiments are shown in Figure 2. These results confirm the previous finding that the natural dispersion rises as the oil-to-water ratio increases. This particular test indicates that the increase is already stable as the oil-to-water ratio increases to 1:20,000.

The percent of oil in the water column (naturally dispersed) increases as the oil-to-water ratio increases up to about 1:20,000. This is very different from the chemical-dispersed situation where the same inflection point is about 1:600.[16] This implies that an important role of chemical dispersants is the stabilization of oil droplets in water. Many more chemically-dispersed droplets can reside in the same volume compared to naturally-dispersed droplets.

STUDY OF THE EFFECT OF HIGH ENERGY ON DISPERSION

High energy studies were initiated using the round flask. The first test results obtained, using ASMB oil and Corexit 9527, are illustrated in Figure 3. The results show that dispersion is increased as the rotational speed is increased. This can be attributed to the increasing amount of turbulent energy in the apparatus. Figure 4 illustrates data from further runs in the round apparatus at two different water levels. Experiments were conducted using the 2 L Erlenmeyer apparatus to confirm the above results. These data are shown in Figure 4 as well. For these tests ASMB oil and the dispersant Enersperse 700 were used. All data show that dispersion increases as energy is increased and that experimental procedure, apparatus, and dispersant have little effect on the overall trend.

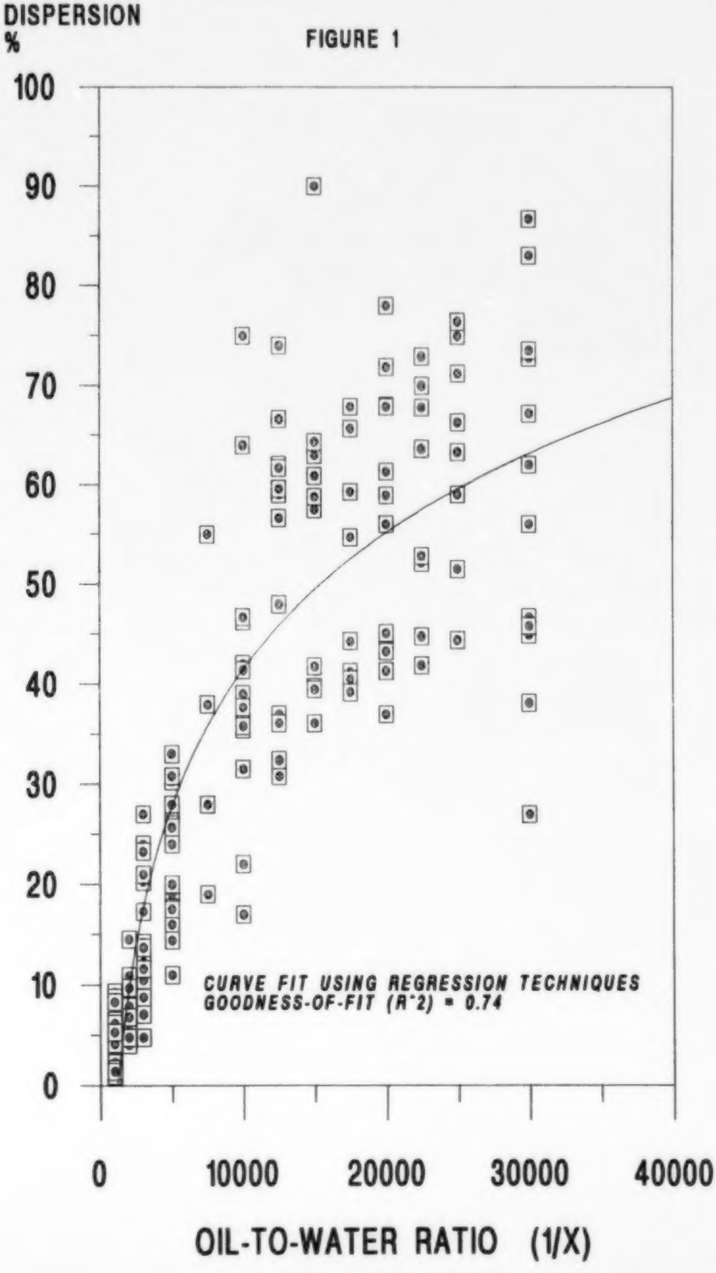
Experiments involving heavier oils (heavier than ASMB) were unsuccessful in that insufficient energy was available to completely disperse the oils or to achieve dispersion without the use of dispersants. The high energy device using a square vessel was developed to address this problem. The square apparatus can generate significant more turbulent energy than the round or 2 L apparatus. This is evidenced by visual appearance, the dispersion of heavier oils and by dispersion of oil without using dispersants. Results of dispersion tests done on ASMB with Corexit 9527 and ASMB without dispersant are shown in Figure 5. This figure illustrates the results of dozens of experiments.

The findings are as follows: that dispersion increases very rapidly from a low value to 100% or nearly so and that natural dispersion onset occurs at an energy level higher than that for chemical dispersion, and finally that the natural dispersion curve has a lesser slope than that for chemical dispersion.

Many confirmation experiments were conducted. Figure 6 summarizes

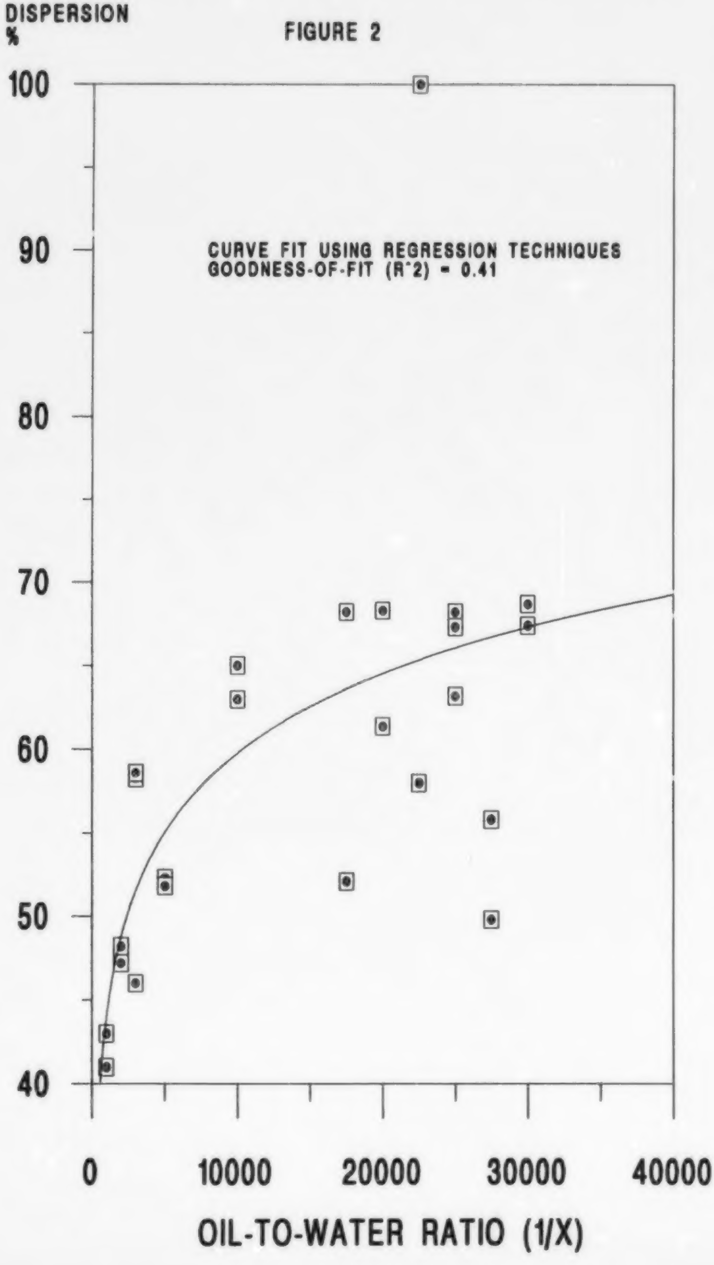
MEASUREMENT OF OIL-TO-WATER RATIO AND NATURAL DISPERSION IN THE LABOFINA

FIGURE 1



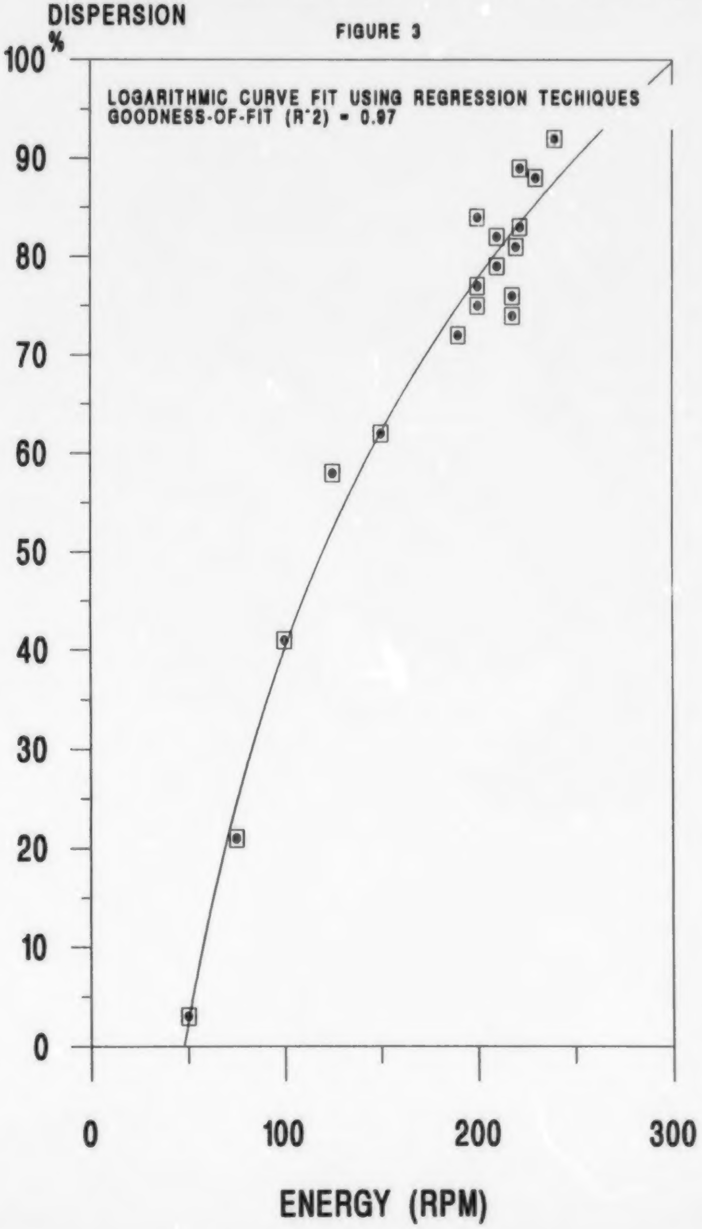
NATURAL DISPERSION AND OIL-TO-WATER RATIO IN THE BLENDER APPARATUS

FIGURE 2



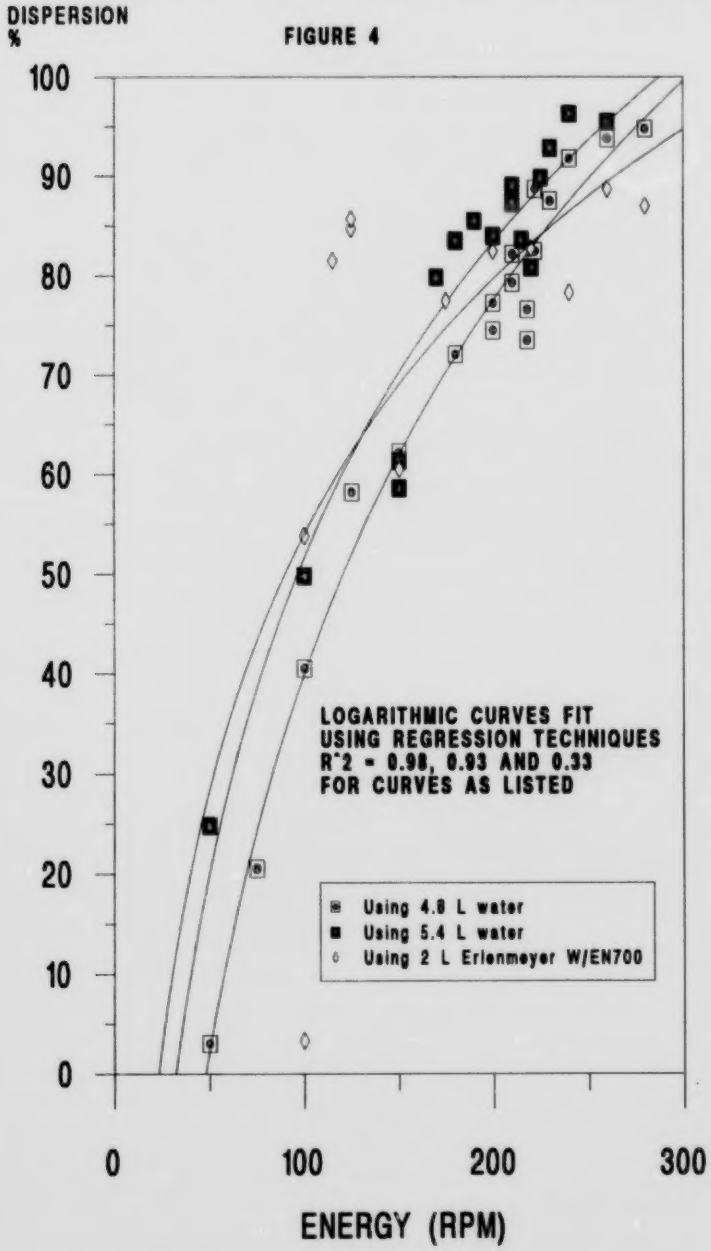
DISPERSION IN THE ROUND HIGH ENERGY APPARATUS

FIGURE 3



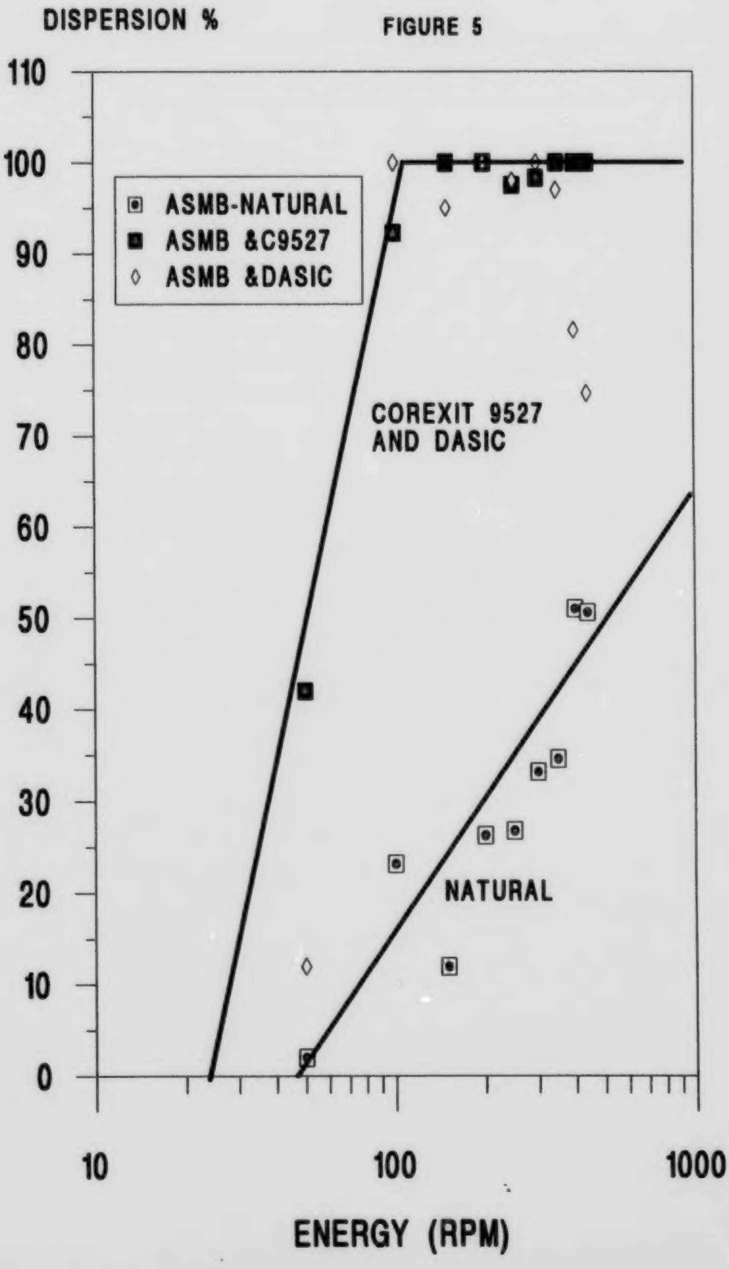
ENERGY RELATIONSHIP IN THE ROUND AND 2-L HIGH ENERGY APPARATUS

FIGURE 4



HIGH ENERGY DISPERSION OF ALBERTA SWEET MIXED BLEND

FIGURE 5



the results of some of these for different oils and dispersant combinations. The energy is sufficient in the high energy apparatus to disperse Bunker C light. Tests on regular Bunker C did not yield dispersion chemically or naturally. During the natural dispersion runs and partially during the chemical runs, the Bunker C grouped into large droplets on the surface. This is indicative that the energy in the apparatus is insufficient to disperse this oil or that this oil is indispersable under normal conditions. Similar trends are seen in the data in Figure 6 as in the previous figure. Onsets of natural dispersion lag the chemical dispersion and the curves of natural dispersion have a lesser slope than those for chemical dispersion. In addition, the two heavier oils tested, North Slope and Bunker C light, do not go to the 100% dispersion level but stay at the 90% level. This is indicative that they are not as readily dispersable as the ASMB and Arabian Light oils. Another trend observed is that the order of chemical and natural dispersion onsets for the oils tested, are the same and are similarly spaced with respect to energy. The effect of chemical dispersant is to decrease the onset of dispersion and increase the amount by a large factor.

Some preliminary work has been done on assessing the difference in dispersion at high and low energies. This work indicates that dispersions formed at lower energies are more stable. Experiments on the amount of oil that remains dispersed in the water column after 24 hours is about 20% for the high energy dispersion and 80% for the low energy dispersion. Interestingly, the amount of dispersed oil remaining in the water column after 24 hours is about the same in both the high and low energy experiments. The difference may well be the amount of dispersant in the droplets. Studies on this aspect continue.

Further investigations were conducted on the dispersion in the region of dispersion onset. This study was done using ASMB, Arabian Light and Norman Wells crude oil. Corexit 9527 was used in the tests and the swirling flask apparatus was used because it is a low energy apparatus and energy variances are much less than in the high energy apparatus. Only one or 2 data values can be obtained on the onset slope with the high energy apparatus. These tests were performed to further investigate the behaviour of dispersion near the onset region and to examine the slope of this region. Results of these tests are illustrated in Figure 7. The best fit curves through these points are linear.

The lower energy portion was studied further using the square high-energy apparatus. Energy was varied by changing the rotation ratio of the shaker in 5 rpm increments. Data are shown in Figure 8. These results again show that dispersion rises rapidly in a linear fashion until complete dispersion is achieved.

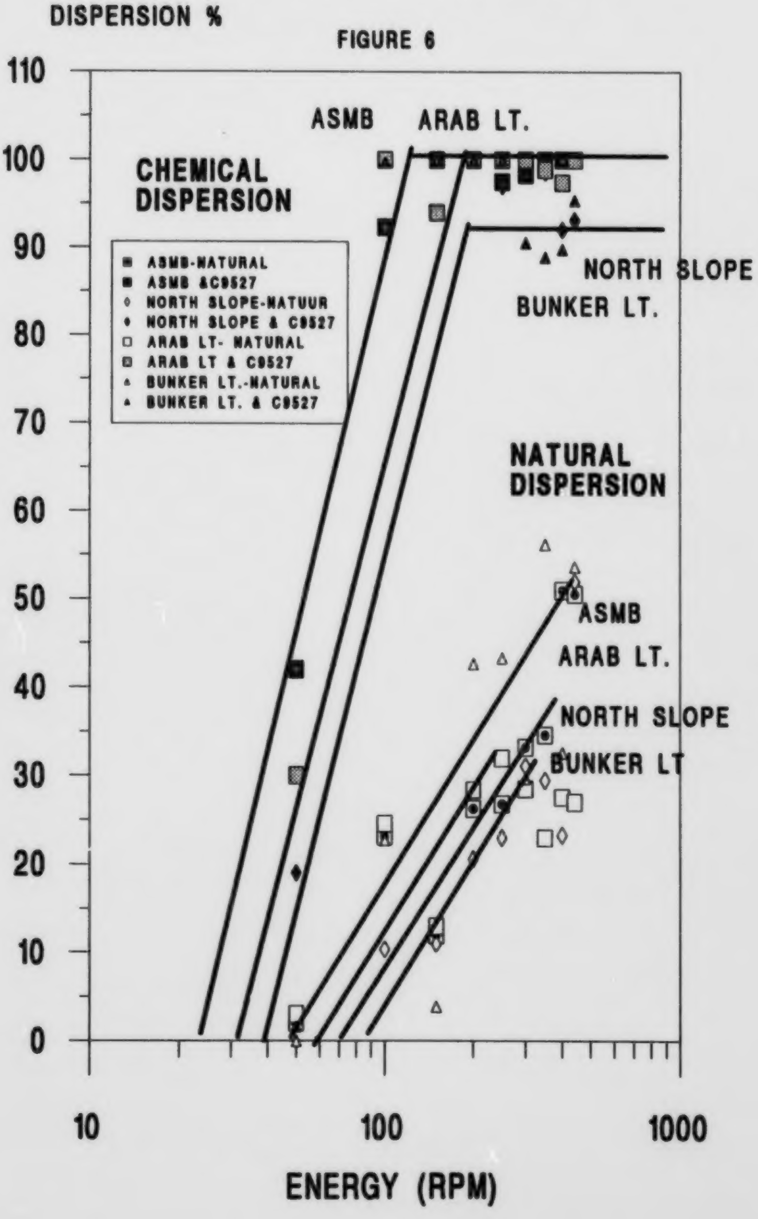
Curve fitting on the data from the square apparatus was done and is shown in Table 3. This shows that the best approach is the use of a combination of two linear curves. Similarly curve-fitting techniques were applied to the natural dispersion curves. These data as given in Table 4 and show that the best approach is a linear function.

SUMMARY AND CONCLUSIONS

The idealized relationships between energy and dispersion are shown in Figure 9, 10 and 11. Chemical dispersion increases with energy in a linear

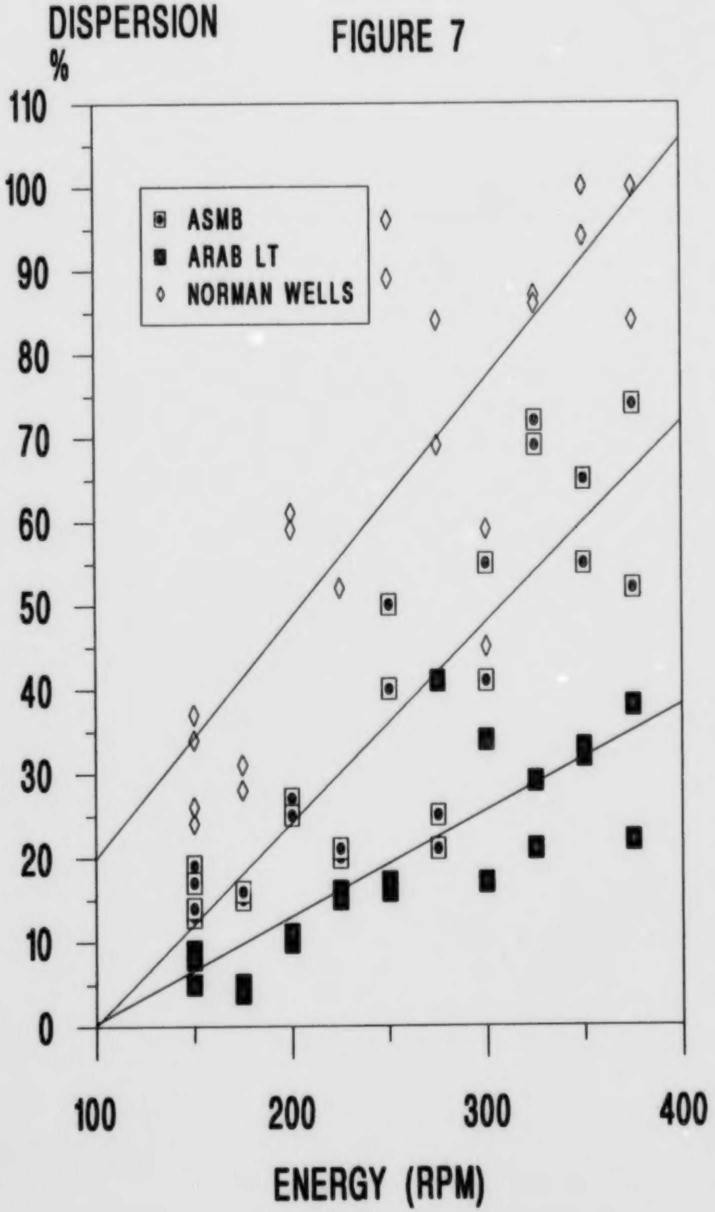
HIGH ENERGY DISPERSION OF FOUR OIL TYPES

FIGURE 6



CORRELATION OF ENERGY AND DISPERSION IN THE SWIRLING FLASK APPARATUS

FIGURE 7



CORRELATION OF ENERGY AND DISPERSION AT THE INITIAL SLOPE OF THE ENERGY CURVE

FIGURE 8

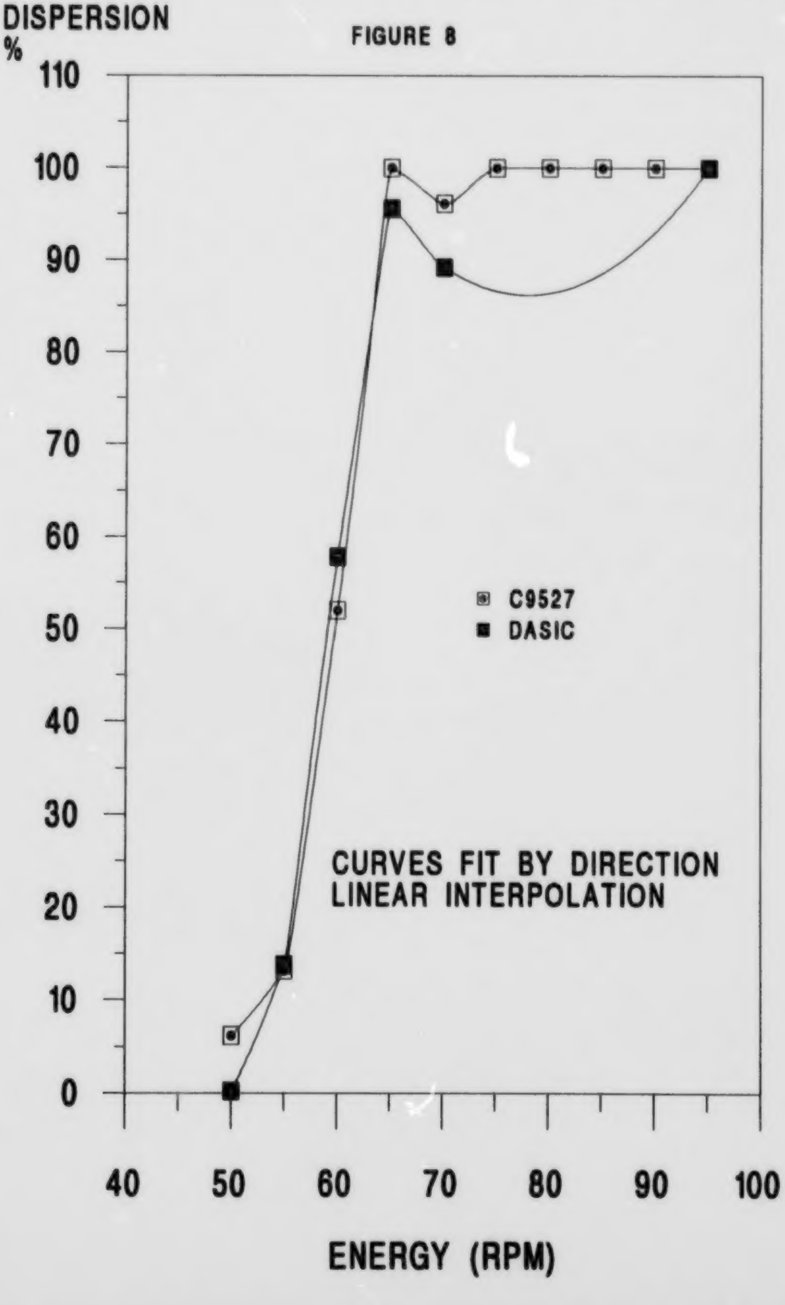


TABLE 2 CORRELATION MATRIX FOR THE HIGH ENERGY CURVE

CURVE	FORMULA	GOODNESS OF FIT (R*R) FOR OIL/DISPERSANT COMBINATION					
		ASMB	ASMB	NORTH SLOPE	ARAB LT.	ARAB LT.	BUNKER
TYPE		C9527	DASIC	C9527	C9527	DASIC	C9527
EXPONENTIAL	Y=A + B EXP(X)	0.35	0.2	0.26	0.31	0.28	0.28
LOGARITHMIC	Y=A + B LOG(X)	0.64	0.32	0.47	0.56	0.44	0.49
3-ORDER POLY	Y= A + B X ....DXXX	0.91	0.82	0.84	0.84	0.84	0.84
4-ORDER POLY	Y= A + B X ....EXXXX	0.99	0.93	0.95	0.92	0.94	0.95
5-ORDER POLY	Y= A + B X ....FXXXXX	1	0.98	0.98	0.98	0.98	0.98
LINEAR	Y= A + B X	0.38	0.11	0.22	0.21	0.32	0.21

GOODNESS OF FIT = UNCORRECTED R^2

STEP - MULTI	A +BX/(1+CXX)+D LOGX	*0.99*
LIN-LOG	Y=A +BX + C LOG(X)	*0.98*
INV-BINOMIAL	Y=AXX/1+BX+CXXX	*0.94*
INV-LINEAR	Y=AX/1 + BX	*0.94*
LOG	Y=A +B LOG(X)	*0.94*
INV-LINEAR	Y=AX/B +CX	*0.94*
STEP - X/LOG	Y=A + BX/C LOG(X)	*0.88*
LINEAR, ALT	Y=A + B (C + X)	*0.88*
EXPON. MOD.	Y=A + B EXP(CX)	*0.88*
STEP - POLY	Y=AX/1+BX+CXX	*0.88*
STEP - SQ/LOG	Y=A+B XX/C LOG(X)	*0.83*
STEP - LOG/SQ	Y=A+B(LOGX)/(CX+DXX	*0.78*

TABLE 3 CORRELATION MATRIX FOR NATURAL DISPERSION

CURVE TYPE	FORMULA	GOODNESS OF FIT (R^2) FOR OIL TYPE		
		ASMB	ARAB LIGHT	NORMAN WELLS
LINEAR	Y=A + BX	0.77	0.63	0.7
LOG	Y=A + B LOG(X)	0.73	0.65	0.73
EXPONENTIAL	Y=A + B EXP(X)	0.81	0.71	0.7

fashion until a maximum is reached. For light oils this maximum is about 100%. For heavier oils this is about 90%. The dispersion curve is very steep, that is only a small amount of energy causes a large amount of change in dispersion. There exists an energy threshold below which little dispersion occurs. Chemical dispersion curves for different oils appear to be parallel. This may be indicative that the mechanism is fixed and only the threshold varies.

Natural dispersion is analogous to chemical dispersion except that the onset occurs at a higher energy and the increase with energy is much less.

Initial work on dispersion quantities show the trend depicted in Figure 11. The effect is to increase the dispersion at low energies, but this has little effect on high energies.

Initial work has also been conducted on particle stability. This shows that there may be significant differences in the stability of dispersions at low and high energies. Tests of stability show that droplets formed at low energy will largely remain in the water column (80% after 24 hours) whereas those formed under high energy do not (20% after 24 hours). The difference does not appear in droplet size, but is probably due to the lesser amount of dispersant in those droplets formed at high energy. This lesser dispersant amount is simply a result of forming many more droplets at high energy with the same amount of dispersant.

The major question these experiments raise is how the energy in these tests relates to that at sea. There are a few observations which indicate that most typical sea energies actually occur at the low end of the energy spectrum shown in the test data presented here. In one test at sea, ASMB and Bunker C light were observed to start dispersing naturally around Beaufort 6.[19] The EKOFISK BRAVO oil was observed to disperse naturally at sea states around Beaufort 5 or 6.[20] It is recognized that turbulent energy is the important factor for dispersion. This energy level correlates with sea state, wave steepness and many other oceanographic factors. Technology does not exist at this time to measure this type of energy at sea and in the laboratory. There may be potential for this in the future with laser doppler or hot wire instruments.

These studies have shed new light on the role of chemical dispersions in the dispersion process. The effect that dispersants have include:

1. lowering of the energy to the onset of dispersion,
2. increasing the amount of dispersion,
3. increasing the mount of oil that a given volume of water can hold, and
4. increasing the dispersant droplet stability in the water column.

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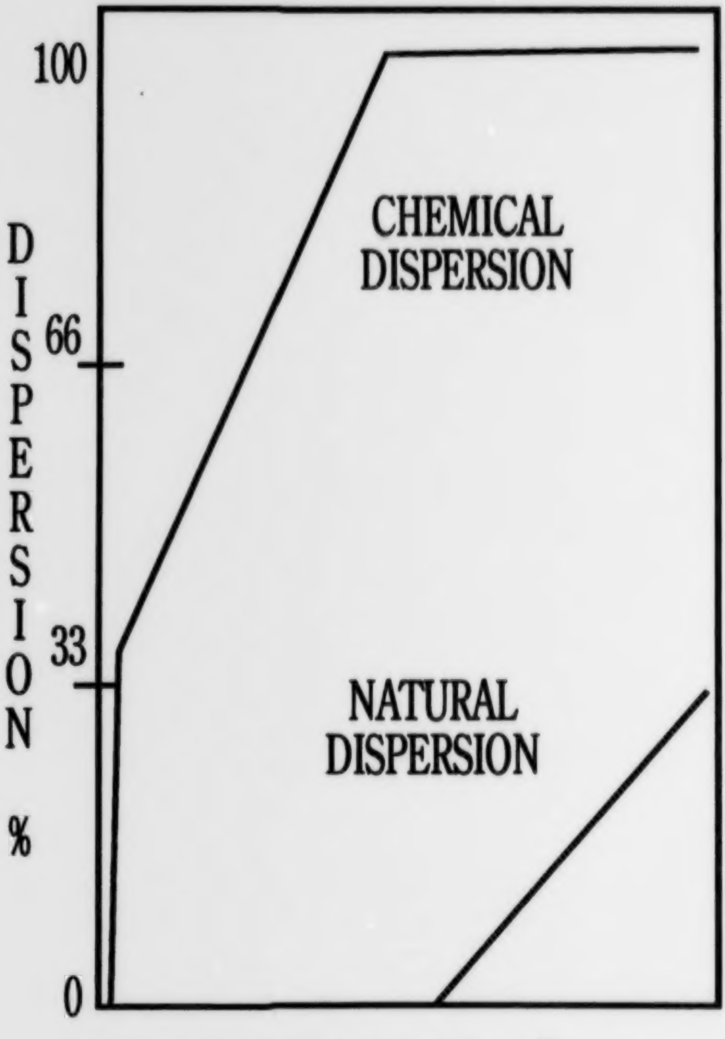
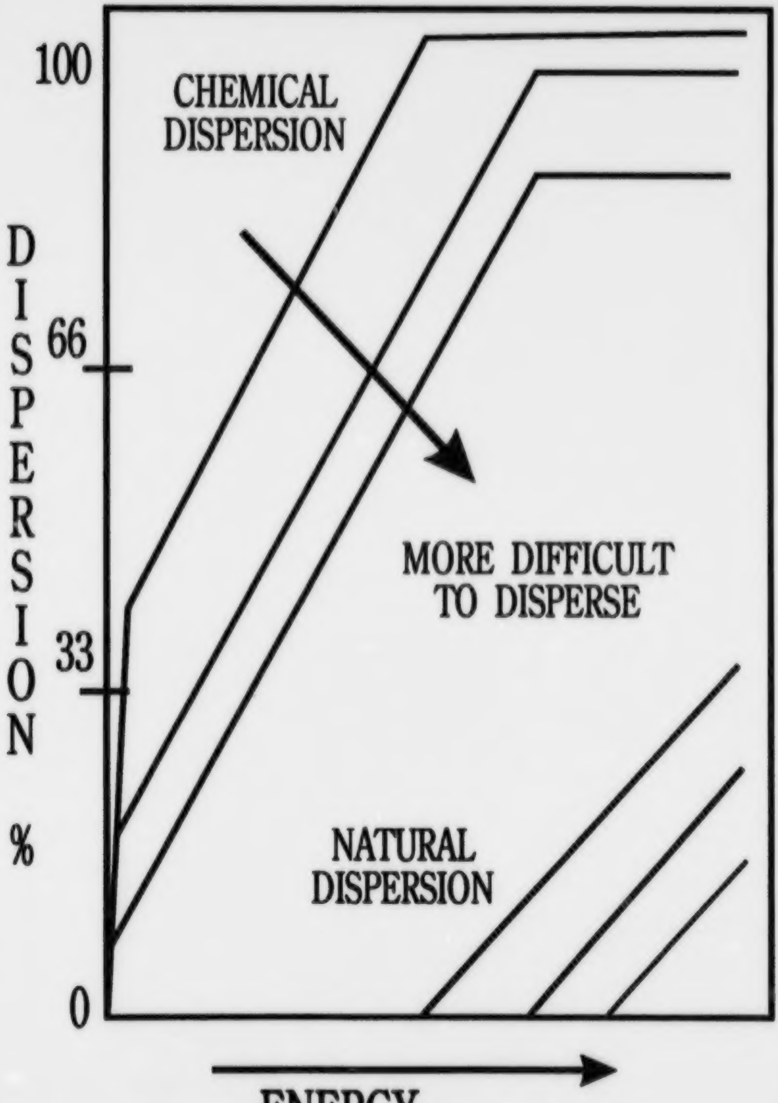
SCHEMATIC OF THE DISPERSION OF A TYPICAL LIGHT CRUDE OIL

FIGURE 9



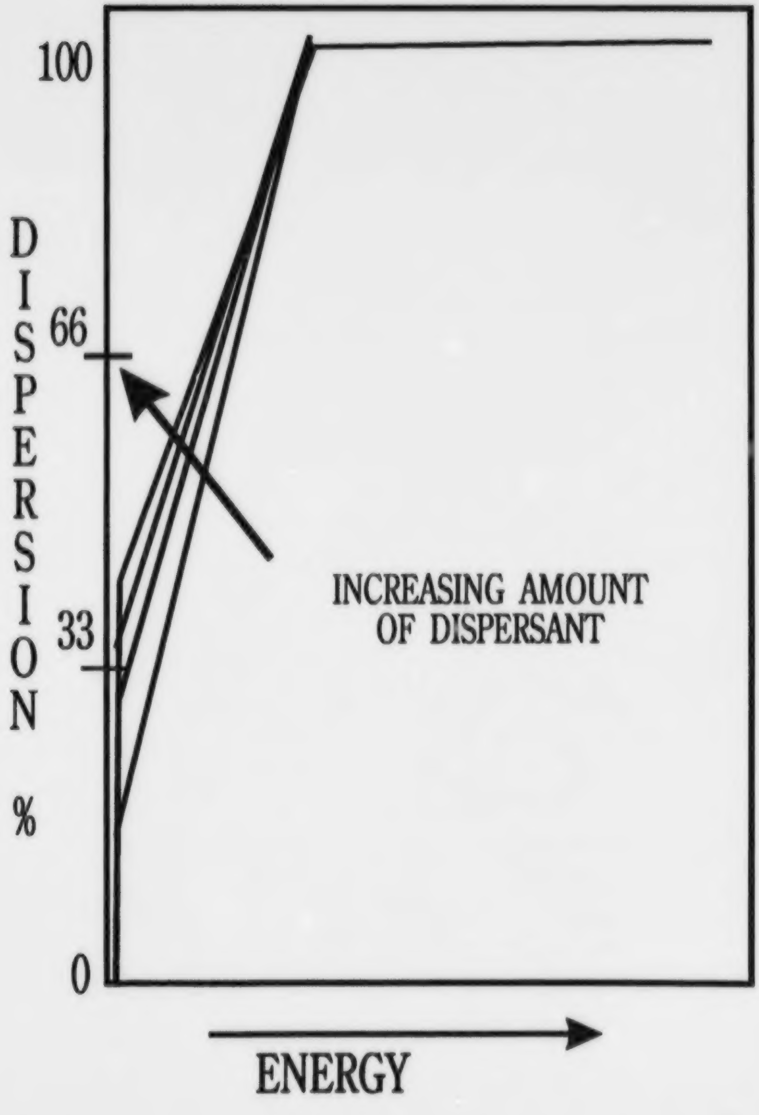
SCHEMATIC OF ENERGY RELATIONSHIP AND DISPERSION WITH DIFFERENT OILS

FIGURE 10



SCHEMATIC OF THE VARIATION OF DISPERSION WITH DISPERSANT AMOUNT

FIGURE 11



THE PHYSICAL-CHEMICAL PROPERTIES OF BITUMEN IN RELATION TO OIL SPILL RESPONSE

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ABSTRACT

Viscous bitumen from northeastern Alberta must be diluted with gas condensate before it can be transported by pipeline to export markets. If a spill of this material occurs, its properties will likely change rapidly as the light condensate evaporates. Laboratory measurements have been made of evaporation rates and the changes which occur in this mixture in viscosity, density, and flash point. The predictions of two fate-of-oil computer models which might be used by on-scene commanders, have been compared to the observed laboratory measurements. The results of the laboratory and computer studies will help spill responders to determine the strategies and equipment needed to combat a spill of this material.

INTRODUCTION

Bitumen or Heavy Oil is produced from the Athabasca Tar Sands of northeastern Alberta at several large extraction plants. While much of the produced bitumen is subsequently upgraded to a synthetic crude oil at on-site facilities, a substantial amount is transported 'as is' by pipeline throughout Canada and to export markets. At its Cold Lake extraction plant, Esso Resources produces about 15000 m^3 of bitumen per day. The bitumen is very viscous and must be transported either at elevated temperatures (as is done around the plant site) or mixed with a suitable miscible liquid to lower its viscosity. Before transport from Cold Lake, the bitumen is mixed with a gas condensate to form a product called Dilbit with properties somewhat like those of a medium gravity oil. Dilbit is moved to Edmonton through the Alberta Energy Company pipeline and from there to a number of export points (including the western U.S., Chicago, and Vancouver). About 950,000 m^3 of dilbit per year is transported from Edmonton to Vancouver through the Trans Mountain Pipeline system for export.

Dilbit is a unique material containing both the remaining heavy ends of reservoired oil which has been water washed and biodegraded and a large light end component of gas condensate which has been added to facilitate pipelining. The exact mix of condensate and bitumen varies slightly from time to time because a number of gas condensate sources are used in the blending. The only specification on the Dilbit is that the summer Dilbit density be less than 927 kg/m^3 at 15°C and that the winter viscosity be less than 250 cSt at temperatures between 0°C and 10°C. To meet these specifications, the gas condensate diluent in the blend may vary from 25 to 30 volume percent in the summer and from 30 to 33 volume percent in the winter.

If an oil spill occurs, the responders first need to know the properties of the oil which they will be required to clean up, because these will determine the nature of the most suitable pick up devices, materials, and procedures. If Dilbit is spilled, its properties may change rapidly because of the large component of volatile condensate. Ultimately, the properties of the spilled material are likely to be those of undiluted bitumen which has properties quite unlike conventional oils. For example, Figure 1 shows the rapid increase in viscosity with decreasing temperature for bitumen (Best and Pauli(1978)). In the temperature range 0°C to 15°C, bitumen has neither the properties of a typical liquid nor those of a solid. Figure 2 shows the density of both bitumen and fresh water and indicates that below approximately 15°C the bitumen will sink. Obviously, very different clean-up techniques will be required for bitumen than for a conventional oil.

For good contingency planning, the behaviour of Dilbit as a function of time after a spill must be known. The laboratory component of this study examines the evaporation characteristics of Dilbit as a function of wind and ambient temperature.

Many computer models of spilled oil movement and fate have been developed both for spill contingency planning and for the use of response personnel during a clean-up operation (Huang (1983), Spaulding (1988)). In the latter case some models can be used to predict oil properties, fate, and movement in the near future based on the tidal and atmospheric conditions prevailing at the time of the spill. Two models, which use different approaches to describe evaporation, were run to determine if they could predict the measured Dilbit evaporation rates based on the known initial material properties.

METHODS AND MATERIALS

Laboratory Study

Evaporation rates were determined by measuring the weight loss as a function of time on samples of summer and winter Dilbit. The sample was placed in a shallow pan on a balance and exposed to a known surface wind velocity and ambient temperature. For evaporation runs at or below 10°C, the equipment was set up in a walk-in environment chamber in which the ambient temperature could be controlled to within +/-1°C. Weight loss curves for temperatures above 10°C were measured with the same equipment placed in a fumehood in a laboratory in which the room temperature could be carefully regulated. The range of wind speeds and temperatures for which weight loss was measured was:

Figure 1

VISCOSITY OF COLD LAKE OIL

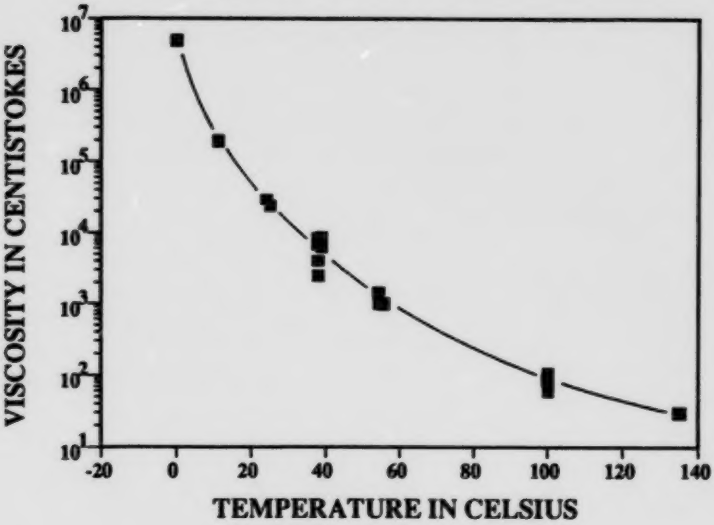
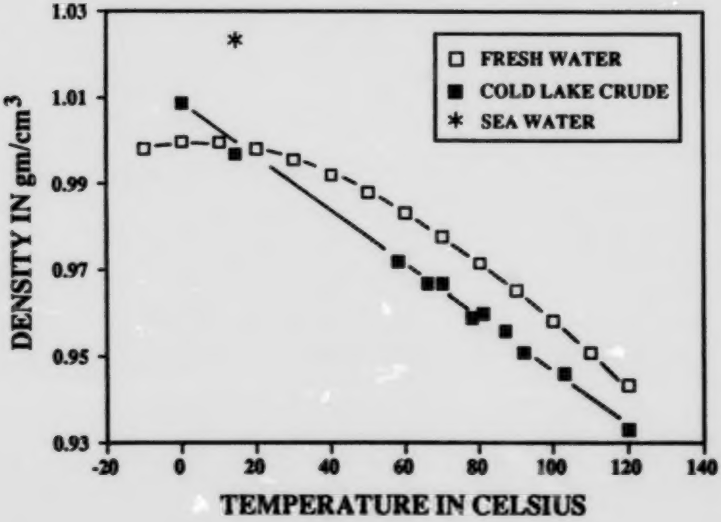


Figure 2

DENSITY OF COLD LAKE OIL



Summer Blend:	Winds	1, 5, and 10 knots
	Temperatures	10, 20, and 30°C
Winter Blend:	Winds	1, 5, and 10 knots
	Temperatures	-10, 0, and 10°C

The wind speeds and temperatures were measured with a Kanomax Model 6511 hot-wire anemometer. Samples were brought to the test temperature and then poured into the trays at the beginning of each run. Approximately 220 gm of sample was weighed into each tray providing a Dilbit film thickness of approximately 3 mm. Weight loss was measured at regular intervals over a 48 hour period. Separate samples were evaporated at room temperature to pre-determined weight losses for the viscosity, density and, flash point analyses. A Brookfield Model LVTD digital viscometer was used for the viscosity measurements while density was determined with a Anton Parr Model DMA 45 densimeter. A Pensky-Martens closed cup flash point tester was used for the flash point analysis.

For these measurements, samples of summer Dilbit and diluent were obtained from Esso's Cold Lake facilities. Upon receipt of the sample in the laboratory, the measured density was 927.7 kg/m^3 at 15°C. The diluent sample was stabilized at room temperature to simulate the field process of flashing pipeline condensates to a stock tank prior to blending with the bitumen. The density of the stabilized diluent was 716.7 kg/m^3 at 15°C.

Samples of the winter Dilbit blend were produced in the laboratory by adding stabilized diluent to the summer blend until the pipeline specification of 250 cSt at 5°C was met.

Fate-of-Oil Model Study

Algorithms as used in two different fate-of-oil models, the Fate of Oil Spill (FOOS) model (Mackay et al. (1980)) and the Applied Science Associates (ASA) Canadian Beaufort Oil Spill model (Reed et al.(1989)) were used to predict the evaporation rates of Dilbit for a specific wind and ambient temperature. Both models in complete form are intended to be run on portable computers and can be used for on-site spill fate predictions. Dilbit properties as reported in Environment Canada's Catalogue of Oil and Oil Product Properties (Bobra (1990)) were used for the FOOS model evaporation algorithm. Distillation data, including the percent volume loss and API gravity for each boiling range cut were required for the ASA Beaufort Sea model. These were generated from a simulated distillation gas chromatograph of the Dilbit. The evaporation rate curves generated by each model algorithm were compared with the rate curves measured in the laboratory.

RESULTS AND OBSERVATIONS

Laboratory Measurements

Examples of the weight loss curves measured in the evaporation experiments are shown in Figures 3 and 4. Data is presented for a specific ambient temperature and Dilbit blend as a range over the wind speeds measured. It is evident that the evaporation rate is mainly temperature dependent since variations in the wind speed have relatively little effect on the evaporation rate. Rapid evaporative loss occurs in the first 5 to 10 hours for both winter and summer Dilbit blends. Even after two days there continues to be a small weight loss due to evaporation of light blend components.

The viscosity, density, and flash point have been measured on both summer and winter Dilbit blends for various degrees of evaporation. Figures 5 and 6 summarize the viscosity and density data as a function of the percent weight loss for the summer blend Dilbit. Similar curves were measured for the winter blend. Again, the data is summarized as a range of values of the temperature, for clarity of presentation. For example, if a summer blend has lost 15% by weight, Figure 5 shows that the viscosity would lie between about 4000 cSt at 30°C and 50,000 cSt at 5°C. Note that summer Dilbit must lose more than 18 weight percent by evaporation before the density exceeds that of fresh water. Losses in excess of 20 weight percent would be required before winter Dilbit would sink in fresh water.

Figure 7 shows the rapid change of flash point as the Dilbit ages. After about 15% of the oil has evaporated, the flash point is similar to that of a medium gravity oil.

Combined with the evaporative weight loss curves, this data enables spill responders to estimate the properties of the material to be recovered. If the ambient conditions at the spill site and the length of time since the spill are known, the evaporative loss curves can be used to estimate the % weight loss. Given the % weight loss, the viscosity, density, and flash point can then be determined from the graphs of material properties.

Computer Model Comparison

Each of the FOOS and ASA models use different approaches to the modelling of evaporation from spilled oil. In the FOOS model, the evaporative exposure concept is used in which the fraction of oil evaporated is given by (Mackay et al. (1980))

Figure 3

SUMMER DIL-BIT BLEND

EVAPORATION AT 20°C

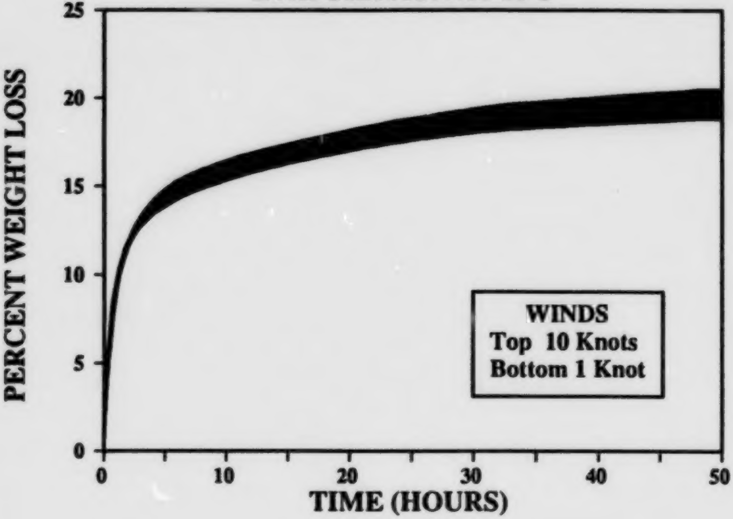


Figure 4

WINTER DIL-BIT BLEND

EVAPORATION AT -10 C

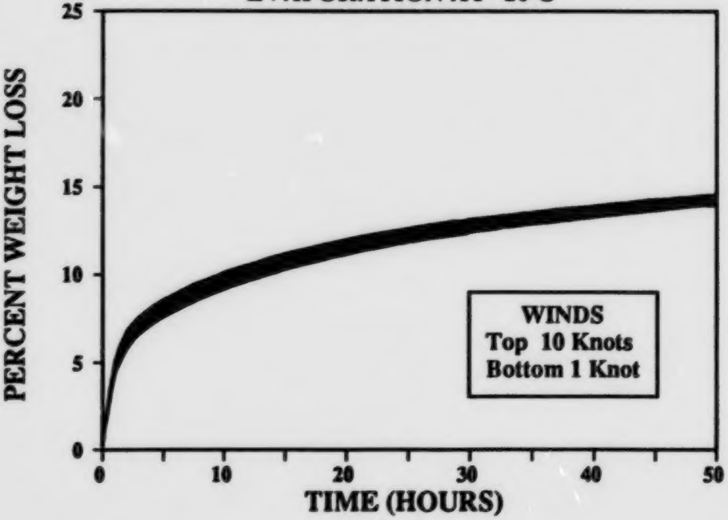


Figure 5

VISCOSITY OF DILBIT vs: WEIGHT LOSS
(Summer Blend)

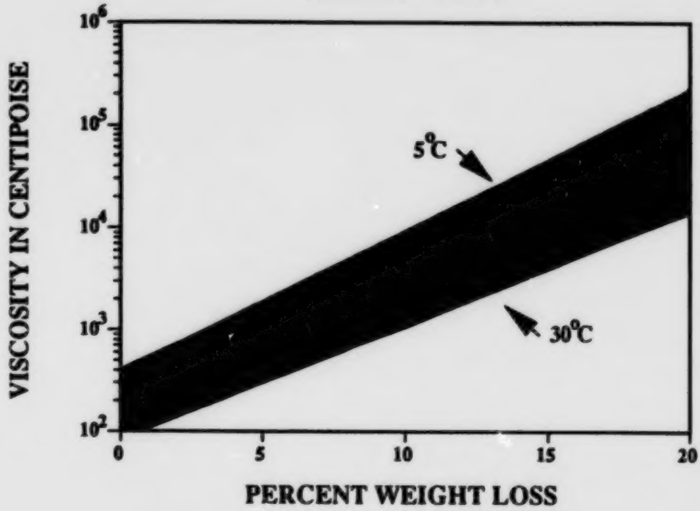
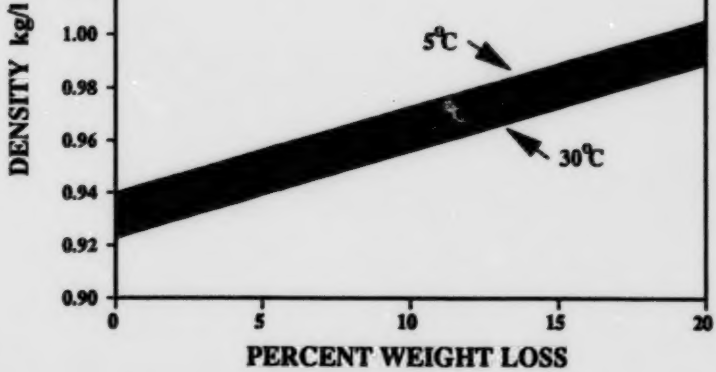


Figure 6

DENSITY OF DILBIT vs: WEIGHT LOSS
(Summer Blend)



$$F = [\ln(P_o) + \ln(C*E) + 1/P_o]/C$$

where $E = (K_m*A*v*t)/(R*T_e*V_o)$ is the evaporative exposure and

$K_m = 0.0048*U^{0.78}*Z^{-0.11}*Sc^{-0.67}$ is the mass transfer

coefficient. 'R' is the gas constant, A the slick area, v the oil molecular volume, t the time, V_o the initial slick volume, T_e the environmental temperature, and P_o the initial liquid vapour pressure. The mass transfer coefficient depends on the wind speed U, a pool size factor Z which is near unity, and the Schmidt number Sc which is approximately 2.7 (Mackay (1973)). 'C' and P_o can be estimated from the API gravity using relations derived by Nelson (1980).

Figure 8 is a comparison of the measured evaporation for a 5 m/sec wind at an ambient temperature of 20°C, with the equation above. A spill volume of 100 m^3 was assumed. A value of about 10^{-5} m^3/mol was used for the average molar volume on the assumption that this was a good estimate for the light gas condensate which initially evaporates from the Dilbit. The model equation generally describes the observed evaporation quite well, particularly during the first few hours. Later however, the model consistently predicts a higher evaporation than is observed. This may be evidence of a 'skin' effect in which the evaporation process is controlled by the diffusion of light components to the surface of the oil slick rather than by the mass transfer of material from the oil to the air. A simple method of correcting the equation is to assume that the vapour phase Schmidt number decreases slightly as the skin on the oil thickens. If the evaporative exposure is modified to

$K_m = (0.0025 - 0.000021*t)*U^{0.78}$ where t is in hours,

then the predicted evaporation compares very favourably with the measured as shown in Figure 9.

The ASA model takes a slightly different approach to evaporation by assuming that the oil consists of a series of components each with a distinct boiling point, API gravity, and molecular weight. A mass transfer rate from the slick is then written for each component as

$$dm/dt = K_m*P_i*A*F_i*M_i /R*T$$

where K_m is the mass transfer coefficient of Mackay
P is the vapour pressure
F is the fraction of the slick remaining and
M is the mass.

For this simulation, boiling points, volume percent, and API gravities were input for 13 boiling ranges. In principle the simulation should predict the evaporation curve well because the properties of the gas condensate are accounted for in

Figure 7

FLASH POINT vs: WEIGHT LOSS
(Winter Blend)

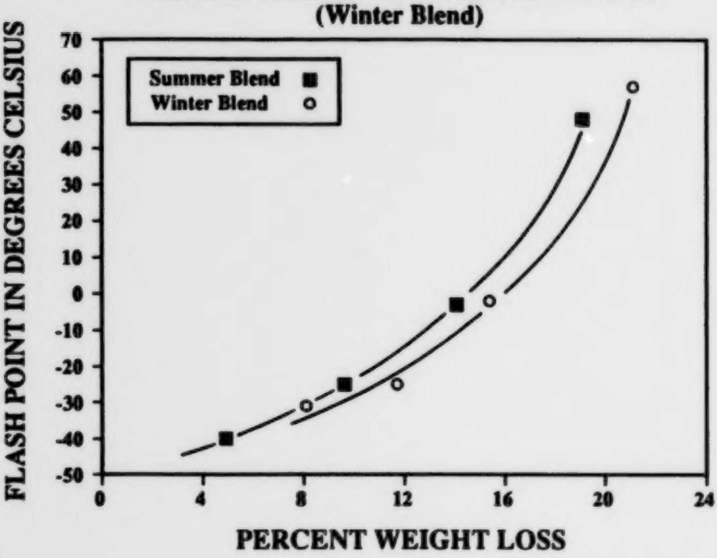


Figure 8

MODEL DILBIT EVAPORATION
(Mackay Model)

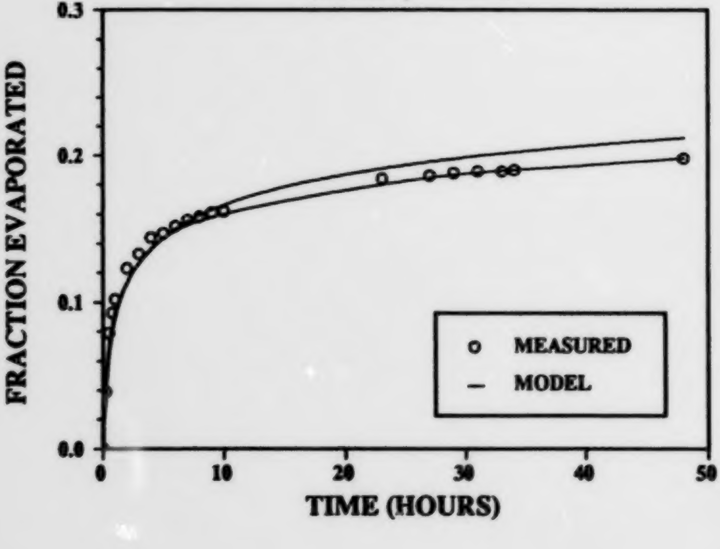


Figure 9
MODEL DILBIT EVAPORATION
(Modified Schmidt Number)

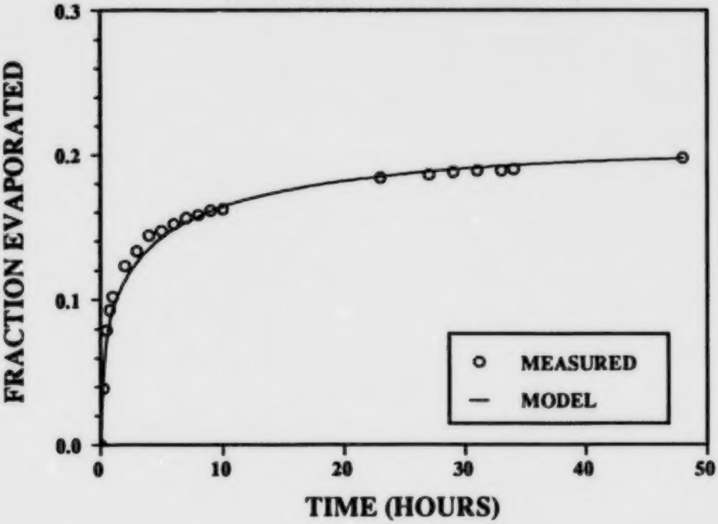
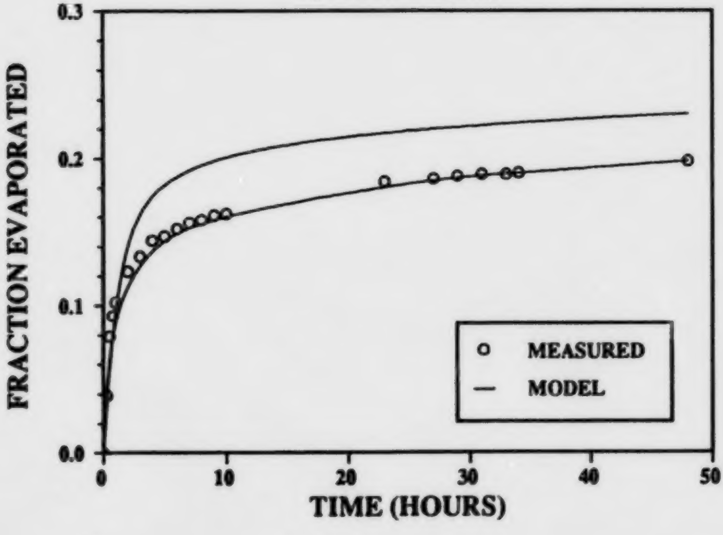


Figure 10
MODEL DILBIT EVAPORATION
(Cozoil Model)



the input data. Figure 10 shows the ASA model result together with the measured evaporation. The general shape of the model curve agrees well with the measured data but the model predicts a slightly higher overall evaporation rate.

CONCLUSIONS

Laboratory measurements of the evaporation of Dilbit blends indicate that rapid changes will occur in the viscosity, density, and flash point during the first few hours of a summer spill. Dilbit, which has viscosities similar to those of a medium weight crude oil when fresh, will begin to exhibit properties associated with bitumen during the first day of a summer spill. During the winter, evaporation will occur more slowly and about two days may be required for the Dilbit to exhibit bitumen-like properties.

Spilled summer Dilbit will remain less dense than fresh water for periods up to 19 hours after the initial spill depending upon ambient conditions and film thickness. During a winter spill evaporation will occur slowly enough that Dilbit will remain lighter than fresh water for more than two days if the temperature is below 0°C. The flash point will likely remain below 0°C for at least the first day of a spill.

Both the FOOS model and ASA model algorithms appear to predict the Dilbit evaporation characteristics if appropriate input parameters are used.

Because of the volatility of the diluent component in Dilbit, the response time will be critical in determining the containment and recovery strategies to be employed in a Dilbit spill.

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Bioremediation of marine oil spills: Scientific validity and operational constraints

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ABSTRACT

This paper examines whether or not bioremediation, that is the artificial enhancement of natural biodegradation, currently has a role to play in oil spill clean-up. The process of biodegradation and the factors likely to affect the rate are first briefly explained. A summary of the results of an extensive literature review undertaken by ITOPF is then presented. From this, conclusions are reached on the use of bioremediation as a clean-up tool, and some recommendations are made for future research programmes.

INTRODUCTION

Bioremediation should first be put into perspective with biodegradation. Biodegradation is the process which brings about the biotic weathering of spilled oil through reactions carried out by some microbes (bacteria, fungi, unicellular algae and protozoa). Enzymes synthesised by the microbes catalyse the oxidation of components of spilled oil to intermediate metabolites and then the same microbes or others degrade these metabolites to carbon dioxide and water.

Bioremediation is defined as any technique that enhances the natural rate of biodegradation; thus bioremediation does not do anything that would not naturally occur over a longer time period through biodegradation.

Bioremediation applications on land and onboard ships have all been accomplished in closed or semi-closed environments where microbes have little or no competition and where conditions can be closely controlled. Much less progress has been made with respect to the application of bioremediation to marine oil spills.

Bioremediation of oil spills is not a new idea: it has been researched since the 1970s and microbial inoculums and fertilisers have been marketed over the same period. The main reason for the current upsurge in interest, both from the general public and commercially, is the great publicity surrounding the efforts by EPA and Exxon to apply bioremediation techniques to the cleaning of beaches in Prince William Sound following the Exxon Valdez spill.

THE PROCESS

Biodegradation can occur anywhere where an oil/water interface, nitrogen, phosphorus, oxygen and a suitable assembly of microbes exists. The microbes live in the water, and use the components of the oil as a source of carbon and energy. In the marine environment, biodegradation of spilled oil will typically be carried out by a community of interacting oil-degrading microbes, within which the predominant group are bacteria.

Such organisms are distributed widely throughout the world's oceans although they tend to be more abundant in chronically-polluted waters, such as those which receive industrial discharges and untreated sewage. Significant numbers of hydrocarbon-dedrading bacteria are also found in deep water (1000 m or more) in sea areas such as the mid-Pacific where oil pollution is minimal (G.D. Floodgate, pers. comm.), thus emphasising that nature invented oil pollution long before man. Each species or strain of bacterium tends to degrade a specific group of hydrocarbons and whilst a range of bacteria exist which between them are capable of degrading most of the wide variety of compounds in crude oil, some components are more resistant to attack than others.

The first step in the degradation of hydrocarbons in oil is often specific to particular species or strains of microbe; the hydrocarbons are oxidised aerobically to intermediates. Aliphatic hydrocarbons and cyclo-alkanes are oxidised to fatty acids (Hiebert, 1990). With aliphatics this pathway is via alcohol and then aldehyde (Watkinson & Morgan, 1990), while with cyclo-alkanes the pathway is via alcohol and then ketone (Trudgill, 1990). Aromatics are oxidised via phenolic compounds (Smith, 1990).

The fatty acid may then be further degraded. The ability to degrade fatty acids is common to many diverse microbes (Hiebert, 1990). Alternatively, the fatty acids may accumulate extracellularly at the oil/water interface; here, in association with other microbial products (see, for example, Rambeloarisoa _et al_. [1984] and Al-Mallah _et al_., 1990), they may act as surfactants. In theory, surfactants can promote either dispersion of oil in the water or the formation of water-in-oil emulsions. Studies on the production of surfactants by marine strains of bacteria are scarce (Al-Mallah _et al_., 1990), as are studies on their mode of action.

There has been discussion that surfactants produced by microbes, as well as intermediate metabolites in general, may be toxic to other organisms (see, for example, Radwan [1991]). However, firm evidence from field situations is lacking; intermediate metabolites are transient (Bartha & Atlas, 1977; Chianelli _et al_., 1991), and may be dispersed rapidly in the water column.

The time-scale for the biodegradation processes, even enhanced, is weeks-to-months-to-years, and certainly not hours-to-days (see, for example, Fusey & Oudot, 1984; Lee & Levy [1989, 1991]; Prince _et al_., 1990).

FACTORS LIKELY TO AFFECT THE RATE

Levels of temperature, nitrogen and phosphorus, oxygen are considered to be the most important influences on rate (Bartha & Atlas, 1977; Cooney, 1990). There are other more fundamental factors such as the chemical composition of the spilled oil, the way in which this composition changes over time due to the influence of various abiotic weathering processes, and the amount of oil/water interface.

Chemical composition of the oil is important because (i) low molecular weight molecules will be quickly lost by evaporation, (ii) low molecular weight aromatics may be inhibitory to microbes until these aromatics evaporate or dissolve (Bartha & Atlas, 1977), (iii) certain components may be amenable to photochemical oxidation, leading to the production of substances inhibitory to microbes (Pengerud et al., 1984; Sveum & Ladousse, 1989), and (iv) certain components of oil (such as cyclo-alkanes, resins and asphaltenes) are considered virtually resistant to biodegradation (Perry, 1984; Cooney, 1990). Since microbes can only act at an oil/water interface, the amount of oil degraded over time will be greater if the oil is dispersed in water or distributed thinly over and through sediments.

Nitrogen and phosphorus are essential for cell growth. Oxygen is required for the oxidation of crude oil components. Nutrients (under normal circumstances) and oxygen are supplied to microbes in dissolved form. Though supplies of both are replenishable, various laboratory and field experiments have confirmed that levels of nitrogen and phosphorus in seawater (and in oil) are limiting in cases of acute oil pollution (compared to the amount of carbon available). On the other hand, surface waters at least are supersaturated with oxygen (O.U.P., 1989).

In shoreline sediments, nutrients and oxygen are replenished by tidal flux, except where nutrients are also provided by terrestrial run-off. A large tidal range can thus be useful in encouraging biodegradation of oil stranded high up on a beach. In addition to nutrients being limiting, the nature of the sediment and degree of oiling will dictate whether oxygen, too, becomes limiting. When the interstitial spaces are heavily clogged with immovable oil, the space available for oxygen-bearing water to move in is small. In oiled fine sediments that have not been disturbed by manual cleanup there may not be much oil deep in the sediment but the tiny interstitial spaces may prevent the movement of oxygen-bearing tidal water through them.

Temperature can influence the rate of abiotic weathering processes, notably evaporation, the amount of oil/water interface, by affecting viscosity, and the solubility of oxygen and components of the crude oil. However, it is considered to have its greatest influence by altering the rate of biochemical reactions. An enzyme that catalyses a biochemical reaction will have an optimum working temperature. In general, a microbe will contain enzymes designed to operate optimally at the ambient temperature characteristic of that time of year. Logically, this would suggest that numbers of oil-degraders should be high the year through, even in temperate latititudes. However, Lee & Levy (1989) document reductions in numbers of oil-degrader bacteria in shorelines in temperate latitudes with the onset of winter and attribute this partly to a reduction in ambient temperature.

INTRODUCTION TO BIOREMEDIATION

Types of product available

Most products incorporate nutrients since the latter are typically the principle limiting factor and are easier to manipulate than oxygen levels and temperature. Nutrient supplements can consist of water-soluble fertilisers, either fast- or slow-release, and/or oleophilic fertilisers. There is potential for adding trace elements in addition to nitrogen and phosphorus.

Some products combine nutrient supplements with microbial inocula. Most of the commercially-available microbial inocula are consortiums of oil-degrading microbes which have been collected from assorted parts of the world; thus, their use at a site constitutes the addition of non-indigenous microbes. In some of these mixed products, the nutrient supplement is tailored to the needs of the microbial mixture.

Open sea v. shoreline application

Bioremediation products are designed to be applied either to oil floating at sea or to oil that has become stranded on shorelines. Although there is some field evidence (Sirvins & Angles, 1986) to support the use of fertilisers on oil at sea, confidence in the efficiency of this strategy is lacking, for the following reasons. Firstly, there will be targetting problems, akin to those found with the aerial application of dispersants (ITOPF, 1987). Secondly, nutrients added directly to the sea are likely to be rapidly diluted, and lost from the slick, even if the nutrient is oleophilic. Lastly, there will be time constraints: since most spills tend to occur in coastal waters, a bioremediation product for use at sea is unlikely to have enough time to act before the oil goes ashore.

In theory, bioremediation is more likely to have success on the shoreline, but its success or otherwise there will depend on numerous factors. These include type of oil (notably toxicity and percentage of resins and asphaltenes); degree of oiling, and depth of penetration; degree of weathering of oil; nature of sediment, and of changes in sediment profile, and of steepness of oiled surfaces if rocky; beach exposure and potential for natural cleaning processes; temperature and oxygen levels; freshwater input to the beach; and species composition and numbers of oil-degraders in the existing microbial community.

Fertilisers alone v. microbial inocula

The approach to bioremediation of marine oil spills has so far been two-tiered: the bottom tier is to add nutrient supplements, and the optional tier is to add microbial inocula with these nutrients.

Depending on the community and environmental conditions, a community of oil-degraders will require an optimal carbon:nitrogen:phosphorus (C:N:P) ratio to degrade oil. When a spill occurs, a huge amount of carbon becomes available to the microbes, but is unaccompanied by the necessary amounts of nitrogen and phosphorus. Nutrient additions are thus undertaken to redress the balance in the C:N:P ratio.

When nutrient supplements are added alone, the main aim is to enhance the rate of biodegradation by the existing indigenous microbial community. Though the technique of nutrient supplements has a sound scientific basis, there is a need to assess the efficiency and toxicity of particular products. The toxicity described here is distinct from any hypothesised toxicity attributed to intermediate metabolites; the sources of potential toxicity would be the compounds in the formulation of the fertiliser (see, for example, Prince et al., 1990).

The addition of microbial inocula (seeding) as a technique has not been studied as comprehensively as nutrient application alone. Seeding involves the application of consortiums of indigenous or non-indigenous oil-degrading microbes. When inocula of microbes are added, supplementary nutrients must be added too, and man-made dispersants may be required to disperse the microbes through the oil.

The main argument against seeding with non-indigenous microbes is that they will be competitively inferior to the existing community of indigenous microbes, because the latter will be adapted to temperature and salinity regimes and the most likely oils to be encountered (see, for example, Lee & Levy [1987, 1989]). Secondly, the inocula may simply not be necessary as was the case in Prince William Sound after the Exxon Valdez spill (Chianelli et al., 1991).

With any nutrient application, there is also the risk of oxygen depletion, through the oxygen being used up by the enhanced microbial community, and that of eutrophication and associated algal blooms occurring in particular circumstances.

The pro-seeding lobby argues that because of the time required for the local microbes to multiply to effective levels, seeding may be necessary. This argument may be more applicable in regions where the oil-degrading community is likely to be less developed (such as areas out of shipping lanes). Laboratory and field evidence comparing the responses of local marine microbial communities to oil spills with those of seeding microbial mixtures is lacking, and thus it is difficult to argue one way or the other for seeding on these grounds. However, it is generally felt by independent microbiologists that numbers of local microbes should be able to come up to stength quickly enough to preclude the need for seeding.

With logistical problems in application, the useful time period for seeding will be shortened. In the remaining "head-start" time available through the use of seeding, the only oil components likely to degrade at a higher rate will be parts of the oil fraction that natural levels of microbes may soon have been able to reduce to equivalent levels.

REVIEW OF FIELD AND LABORATORY EVALUATIONS

Interpretation of results from evaluations

Both laboratory and field experiments have their uses. Whilst laboratory experiments facilitate greater control over conditions, monitoring and replication, they are often unrepresentative of field situations due to their closed nature. Field experiments permit the product to be tested in more appropriate conditions, but collection of data and its interpretation may be more difficult.

The latter may be due firstly to heterogeneity in the distribution and concentration of oil. Oil distribution can be controlled where chosen sediments are deliberately oiled, but in an accidental spill the heterogeneity of oil distribution and concentration will tend to be greater. Where the spatial resolution of sampling is insufficient, this heterogeneity can cause very large standard deviations compared to mean values, rendering it difficult to illustrate results statistically.

Data interpretation difficulties may also be due to the presence of conditions which vary between control and treatment sites and between treatments, and which are likely to affect results. These conditions may include sediment type, freshwater input, abiotic weathering processes and microbial processes. If they are not taken into account and quantified, they cannot be controlled for in analyses. Thus some peripheral assessment work may be needed to investigate whether or not, for example, a stream running through the test plot is affecting biodegradation significantly.

The hitherto accepted indices of biodegradation of ratios of n-C_{17}:pristane and n-C_{18}:phytane appear to have limitations. Pristane and phytane (iso-alkanes) have been taken to be "conserved" markers, with the acknowledgement that they are indeed degraded, but much slower than the homologous n-alkanes. However, results from the bioremediation project in Prince William Sound suggest that these markers are degraded almost as fast as their homologues (see, for example, EPA [1990] and Prince et al. [1990]).

If the oil-degrading community varies spatially and temporally, rates of pristane and phytane biodegradation may similarly vary, such that the ratio could no longer be relied upon.

Microbial inocula

Various commercially-available inocula were developed and promoted in the 1970s, though some of these appear to be no longer available. Today, there are several companies manufacturing products, mostly based on bacteria, which they describe as suitable for bioremediation of oil spills in the marine environment.

Most of the manufacturing companies have been previously involved in the treatment of waste materials in closed or semi-closed systems, and in expanding into the marine environment, the problems of aqueous open systems have not been taken into account. In many products the bacteria used have been isolated from freshwater environments and the stocks which perform well in higher salinities then selected. Some of the products have never undergone field trials in the marine environment.

From a thorough examination of the material available on commercial inocula, there is no adequate statistical field evidence that any of the products enhance biodegradation significantly compared to appropriate controls (see Mauro, 1990; Mauro & Wynne, 1990; Venosa et al., 1991; assorted corporate literature). In some cases, this conclusion is attributable to the inadequate experimental design of the trials.

Visual results from trials may in part be due to the dispersive action of surfactants produced by the microbes. The relative effects of biodegradation and any dispersion caused by microbially-manufactured surfactants should be evaluated in trials assessing the efficiency of bioremediation products. Bartha & Atlas (1977) state that "There is little doubt that losses by [physical dispersion] sometimes lead to overly high estimates of biodegradation, especially in open test systems."

Oleophilic fertilisers

The literature reveals that at least six oleophilic fertilisers have so far been used in marine oil degradation experiments (see Bartha & Atlas, 1977; Olivieri et al., 1976; Branchart et al., 1985; Sirvins & Angles, 1986; Fusey & Oudot, 1984; and Scherrer & Mille, 1989). Only three of these appear to have undergone the scrutiny of independent researchers. Inipol EAP 22 (TM) has received the most attention by virtue of its being chosen for use in the EPA and Exxon bioremediation project in Prince William Sound following the Exxon Valdez spill.

Inipol is a microemulsion with an "optimised" (CECA, 1990) C:N:P ratio. Originally, it was developed for use offshore (Halmo, 1985), but Sveum & Ladousse (1989) concede that little or no enhancement of biodegradation has been recorded from using Inipol in oil-on-water experiments.

Field and laboratory experiments with oil-on-sediment have produced contrary results. The work of some researchers suggests that Inipol does enhance biodegradation (e.g. Sirvins & Angles, 1986; Sveum, 1987; Sveum & Ladousse, 1989), while that of others suggests it does not (see, for example Lee & Levy, 1989; Lloyd & Latchford, 1991).

The mechanism of action of Inipol is still unknown. Inipol contains a mild surfactant (oleic acid), and it has been suggested that this component could give it some chemical rock-washing properties. However, EPA and Exxon (see, for example, Chianelli et al., 1991) have performed laboratory experiments, corroborated by anecdotal field evidence, the results of which preclude this mode of action.

Under a hypothesis presented by Chianelli et al. (1991) and Jahns et al. (1991), any fertiliser (oleophilic or water-soluble) could promote the removal of oil from rock surfaces by enhancing a flocculation process that occurs between oil and fine clay particles. From their results, Lee & Levy (1989) state that the oleic acid in Inipol promotes the growth of oleic acid-degraders, rendering the application of Inipol ineffective. Lloyd & Latchford (1991) observed an inhibition of oil degradation in the Inipol treatment over the first six days of their field experiment (which ran for 25 days), and suggested that degradation of oleic acid (in preferance to oil hydrocarbons) was the reason.

Results of laboratory experiments reported in Lee & Levy (1987), Sveum & Ladousse (1989) and Safferman (1991) suggest that large amounts of nitrogen are lost very fast once Inipol comes into contact with water; this observation reduces the significance of the fertiliser having an "optimised" C:N:P ratio.

Water-soluble fertilisers

The water-soluble fertilisers used in oil experiments have all come from agricultural or horticultural sources. Two slow-release fertilisers have been investigated thoroughly by the EPA as a result of their use in the EPA/Exxon bioremediation project in Prince William Sound following the Exxon Valdez spill (Glaser et al., 1991). Fast-release water-soluble products have been used in more studies, and have frequently been agricultural fertilisers.

Published information on the efficiency of slow-release fertilisers is available in Prince et al. (1990) and Glaser et al. (1991). In Snug Harbor in Prince William Sound, fertiliser briquettes produced no visible effects, though there were apparently "significant" changes in oil composition (Glaser et al., 1991). No microbiological analyses are presented. Safferman (1991) states that the briquettes show a slow, constant release of nitrogen. In Passage Cove, fertiliser granules were applied in association with Inipol, so assessing the efficiency of the granules as distinct from that of the Inipol is difficult. Visible improvements were apparent after two weeks (compared to the control beach) (Glaser et al., 1991); however no results from chemical or microbiological analyses are presented.

The use of fast-release agricultural fertilisers periodically mixed in with oily aerated fine-course sand on a low-energy beach is recommended by Lee & Levy (1989, 1991) on the basis of field experiments conducted over one year in Nova Scotia. They state that the use of agricultural fertilisers has operational advantages, since the fertilisers are readily available and inexpensive (Lee & Levy, 1989). Senstad (1980) is also of the opinion that fast-release fertilisers have the potential to enhance biodegradation on low-energy shorelines.

CONCLUSIONS

There is insufficient evidence to support the idea that the addition of indigenous or non-indigenous microbes to oil, either whilst it is at sea or when it has become stranded on a shoreline, will enhance biodegradation. The only field experiments where microbes have been added have been with commercially-available non-indigenous microbes. It is hoped that more rigourous field testing of inoculums will occur, and it is suggested that the emphasis should be on indigenous microbes. The problems inherent in field testing are fully appreciated, and such tests are not expected to yield easily discernible results. They should be carried out in association with laboratory tests, and if possible by non-commercial organisations.

The main problems with application of fertiliser to oil slicks at sea are dilution of nutrients and the short time available for action before the oil goes ashore.

The most promising results come from field and laboratory tests where nutrients have been applied to oiled sediment. However, the research field is not yet sufficiently mature to allow concrete conclusions to be made about the viability of nutrient additions to shorelines. Too many unanswered questions about cost-effectiveness and environmental concerns remain for bioremediation to be recommended for use other than experimentally.

This is due to (i) some of the current reports and papers being inadequate in their detail (see recommendations below), and (ii) problems encountered in some field studies, as outlined earlier.

RECOMMENDATIONS

The following recommendations are made for further research on bioremediation products which would yield the type of information required for judgements to be made on their usefulness:

(i) efficiency should be judged by an independent organisation (preferably governmental), using an accepted protocol,

(ii) the statistical techniques to be used for subsequent data analysis should be decided in advance, and the experiment should be designed accordingly; the aim should be to show statistically that biodegradation in the treatment is being significantly enhanced compared to an appropriate control,

(iii) changes in activity and numbers of microbes should be monitored in in association with changes in oil chemistry (Floodgate, 1984; Lee & Levy, 1987, 1989). Though a link between the two is difficult to make statistically, following the two processes together facilitates decision over whether changes in oil chemistry are due to changes in activity and numbers of microbes and *vice versa*,

(iv) the numbers and activity of oil-degrading microbes should be monitored separately from those of microbes in general that obtain their carbon from the oxidation of organic molecules (known as heterotrophs),

(v) oil analyses should ideally include not only gas chromatographic analyses of *n*-alkanes but also gas chromatographic/mass spectroscopic analyses of components of the unresolved complex mixture and analyses of resins and asphaltenes, because some quantification of the biodegradation of non *n*-alkanes would be useful,

(vi) the decision on whether or not to use *n*-C_{17}:pristane and *n*-C_{18}:phytane ratios as indices of biodegradation should be carefully evaluated; there should be some accompanying analysis of rates of biodegradation of pristane and phytane between sites and over time.

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Monitoring Hydrocarbons in Beaufort Sea Sediments and Organisms: Implications for Oil Spill Monitoring

by

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Introduction

A study was initiated in the Alaskan Beaufort Sea in 1989 in order to monitor the marine environment for inputs of anthropogenic hydrocarbons resulting from activities related to oil drilling and exploration, as well as inputs due to soil spills. This study represents a continuation of the Beaufort Sea Monitoring Program (BSMP, 1984 - 1986), after a three year sampling hiatus and continuing drilling and exploration activities in the study area. The 1989 BSMP was designed to monitor sediments and selected benthic organisms for hydrocarbons so as to infer any changes that might have resulted from drilling and production activities.

The objectives of this study were as follows: (1) To detect and quantify changes in the concentrations of hydrocarbons in the Beaufort Sea sediments and sentinel organisms that may (a) result from discharges from outer continental shelf (OCS) oil and gas development activities, (b) adversely affect or induce adverse effects on humans or on the environment and (c) influence federal OCS regulatory management decisions. (2) To identify potential causes of these changes.

Method and Analysis

Study Location

The Beaufort Sea, which is part of the Arctic Ocean, lies north of Alaska and western Canada, at latitudes approximately 71°N and 143 to 153°W longitude (Figure 1). The BSMP study area was divided into eight regions, based extending from Cape Halkett on the western end of Harrison Bay to Griffin Point, east of Barter Island. These regions were deliniated based on physical and geochemical features. Regions 1,2,3,4,and 5 were low risk regions (areas of low activty during the three year sampling hiatus). Region 6 was a high risk region. The study area was extended to include two new regions 7 (low risk region) and 8 (high risk region). Region 7, located east of Kaktovik and Barter Island was added because of several Amoco prospects and lease sale 97, as well as potential influence of drilling in the Mackenzie River Delta. Region 8, located in the vicinity of the the Endicott Island development area, increased coverage of this offshore drilling facility. A series of forty-nine (49) stations were sampled during this program, thirty-nine (39) of which had been previously studied in the 1984-1986 BSMP.

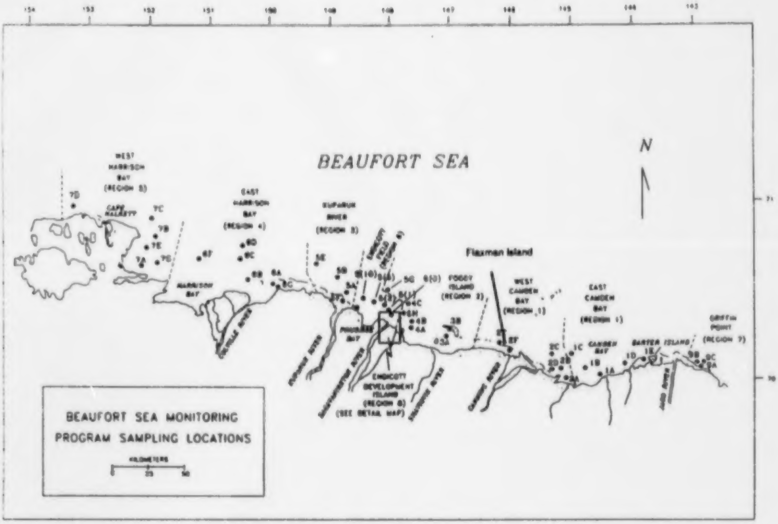

BEAUFORT SEA
N
WEST HARRISON BAY (REGION 5)
CAPE HALKETT
7D
7C
7B
7E
7A
7G
EAST HARRISON BAY (REGION 4)
HARRISON BAY
KUPARUK RIVER (REGION 3)
Flaxman Island
FOGGY ISLAND (REGION 3)
WEST CAMDEN BAY (REGION 1)
EAST CAMDEN BAY (REGION 1)
CAMDEN BAY
BARTER ISLAND
GRIFFIN POINT (REGION 7)
PRUDHOE BAY
ENDICOTT DEVELOPMENT ISLAND (REGION 8) (SEE DETAIL MAP)
2C
1C
2D
2B
1B
1A
1D
1E
2A
3A
3B
4A
4B
BEAUFORT SEA MONITORING PROGRAM SAMPLING LOCATIONS
KILOMETERS
0
25
50

Figure 1 **Location of Regions and Sampling Stations for the 1989 Beaufort Sea Monitoring Program**

Sampling Design and Field Method

The sampling design combined two basic elements. The first element was an *area-wide approach* in which stations were treated as replicates of eight (8) specific geographic regions. The second element was an *activity-specific* approach, which focused on the potential establishment of metal or hydrocarbon concentration gradients with distance from the Endicott Production Field in Prudhoe Bay. Stations were sampled in August, 1989. A station, in this study is defined as an area within 0.8 nmi of a documented location (station center), which was based on the assumption that the variablity in sediments and organism chemistry over this area was known, based on previous BSMP data. Sediment and bivalves were sampled using a modified 0.1 m^2 Van Veen grab sampler. Amphipods were collected using baited minnow traps. All samples were frozen immediately after collection in pre-cleaned glass jars.

Analytical Method

Details of sample preparation and instrumental analysis are presented in Boehm et al., 1990. Bulk sediment was analyzed for a suite of saturated and aromatic hydrocarbons, as well as for grain size and total organic carbon (TOC). Benthic bivalve molluscs representative of several feeding types (*Astarte borealis*, *Portlandica artica*, *Macoma calcarea*, *Cyrtodaria kurriana*) were collected from those stations which were sampled previously and were analyzed for saturated and aromatic hydrocarbons. The benthic amphipods *Anonyx sp*. were collected and analyzed as well. The analytical scheme for sediment and tissue preparation for hydrocarbons is outlined in Figure 2. Instrumental methods for hydrocarbon analysis consisted of gas chromatography with flame ionization detection, for the f1, or saturates fraction and gas chromatography/mass spectrometry for the f2 or aromatic fraction. Instrumental conditions are listed in Table 2. The samples for each station were analyzed as either pooled grab replicates or three individual replicates. Statistical techniques for data analysis included a variance component model, fixed effects analysis of variance, correlation analysis and an analysis of covariance.

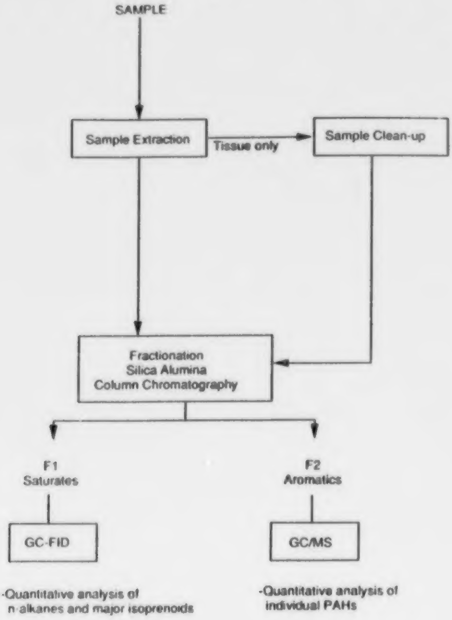

SAMPLE
Sample Extraction
Tissue only
Sample Clean-up
Fractionation
Silica Alumina
Column Chromatography
F1
Saturates
F2
Aromatics
GC-FID
GC/MS
-Quantitative analysis of
n-alkanes and major isoprenoids
-Quantitative analysis of
individual PAHs

Figure 2 **Analytical Scheme for Hydrocarbons in Sediments and Animal Tissues**

Study Results and Discussion

Framework for Interpretation

In previous reports from the BSMP, it had been concluded that the sediments from this area differ from OCS sediments in both hydrocarbon content and composition, in that they contain significant background concentrations of both biogenic and fossil fuel derived hydrocarbons. The major sources of these hydrocarbons are the rivers which empty into the Beaufort Sea, through a terrain which is mostly tundra, and has coal and shale outcrops as well as natural petroleum seeps (Boehm et al., 1987). These rivers, and especially the Colville River, are important contributors of sediment to the study area. Erosion of the coastline and river banks contribute to offshore sediment loadings as well. With the significant natural background hydrocarbon concentration, it may be difficult to detect, using conventional techniques, small inputs of petroleum resulting from drilling and exploration. In such a situation, specific diagnostic saturated and aromatic ratios can aid in the evaluation of change due to drilling activity, or accidental oil spills.

Saturated Hydrocarbons in Sediments.

In general, little change was seen in the concentrations of saturated hydrocarbons or their composition in sediments collected from the 1989 survey, compared with the 1984 - 1986 results (Figure 3). Previous work (Boehm et al.,1987) reported concentrations for total saturates (TOT) of 2 µg/g to 52 µg/g throughout the study area. The area of the highest concentration was reported to be the East Harrison Bay area (mean TOT = 30.2 µg/g, which was shown to be strongly influenced by discharge from the Colville River. The Kuparuk River and West Harrison Bay regions also had high TOT concentrations due to discharges from the Kuparuk and Colville Rivers. The effects of riverine discharge, combined with physical factors such as currents and tides cause these regions to be enriched in fine grained material, relative to the other regions. The 1989 survey showed similar relative results, with East Harrison Bay having a mean TOT concentration of 8.8 µg/g (Figure 4). However, the overall range of the saturates was less and the absolute concentrations lower in 1989 sediments.

While the concentrations of saturates varied markedly between stations and regions, the alkane composition of sediments was fairly consistent throughout the study area, a finding that was also described in the 1987 report. Alkane distributions were dominated by biogenic higher-molecular-weight alkanes (nC21-nC34), with a marked odd-even preference. Low-molecular-weight hydrocarbons (LALK) were present in most sediments at levels up to 20% of the total alkane (TALK) content. The ratio of LALK/TALK varied between 0.14 and 0.21 for all regions (Figure 5) and did not differ significantly from the other years (Figure 6), suggesting that no regions were affected by oil-related inputs from drilling activities since the previous sampling in 1986. Similarly, the pristane/phytane ratio was fairly constant throughout all of the study regions (Figure 7). Pristane occurs naturally in sediments, being derived from a side-chain of chlorophyll, while phytane is an isoprenoid hydrocarbon component of oil.

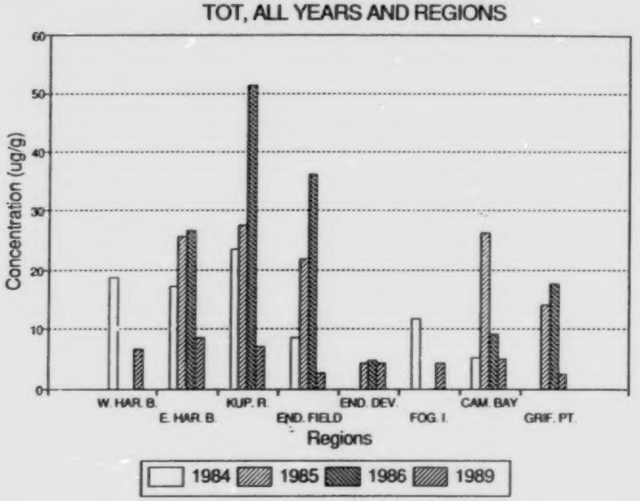


Figure 3 Mean Concentrations of the Total Saturated Hydrocarbons (TOT) in Sediments for all Four Years in all Study Regions.

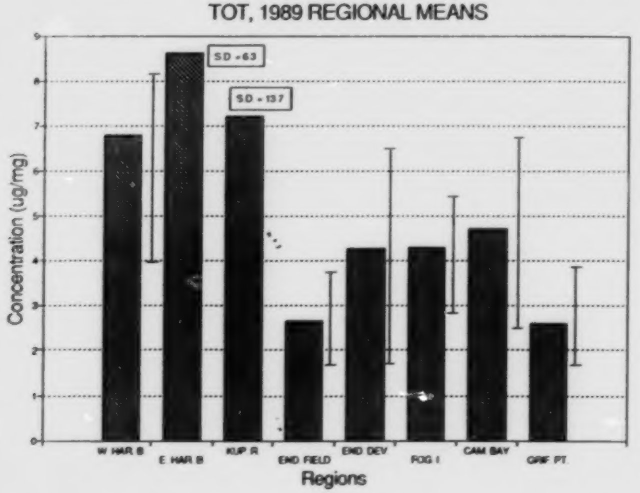


Figure 4 Regional Mean Concentrations of Total Saturated Hydrocarbons (TOT) in Sediments for all Regions in 1989. Error Bars Represent the Standard Deviation (±.5 SD).

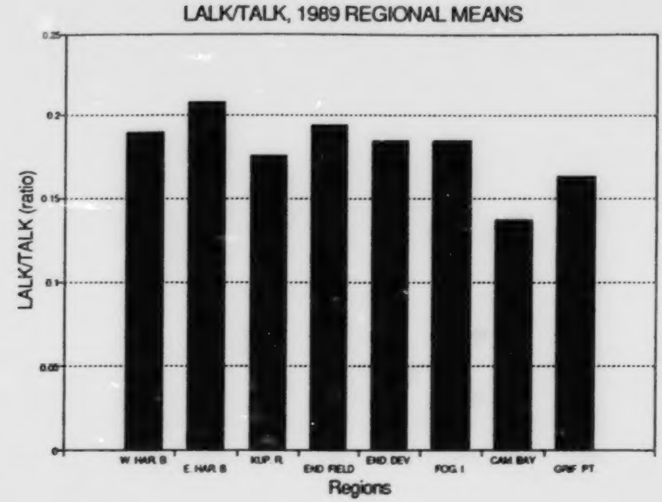


Figure 5 1989 Regional Mean Values of the Lower Molecular Weight Alkanes (LALK) to the Sum of the Normal Chain Alkanes (TALK).
The Value for Prudhoe Bay Crude Oil is 0.68.

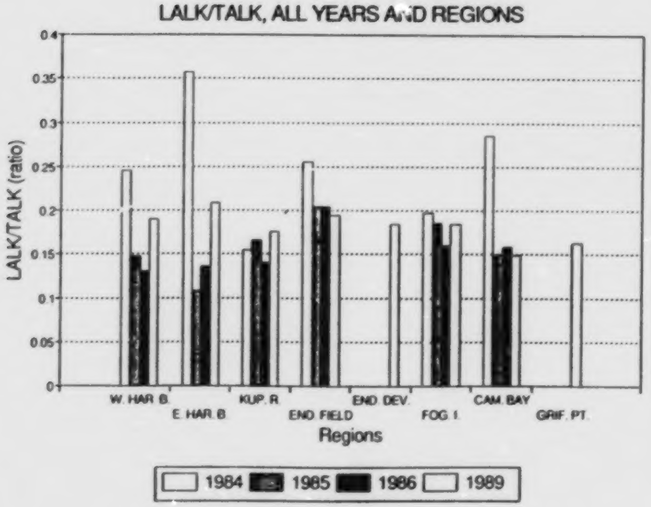


Figure 6 Four Year Regional Mean Values of the Lower Molecular Weight Alkanes (LALK) to the Sum of the Normal Chain Alkanes (TALK).
The Value for Prudhoe Bay Crude Oil is 0.68.

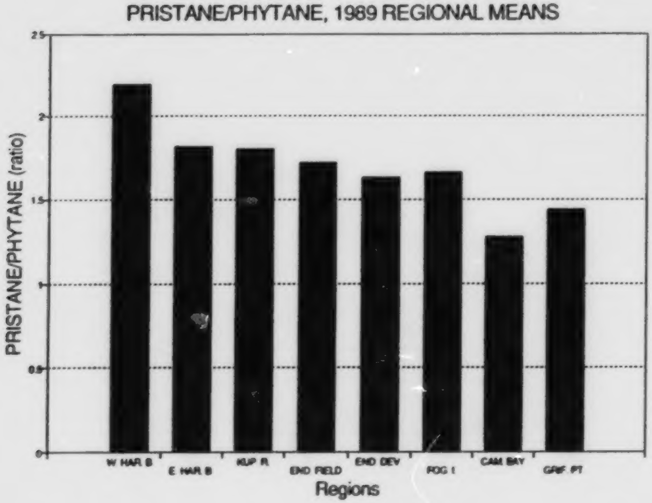


Figure 7 Mean Values of the Ratio of Pristine to Phytane (Pris/Phyt) in Sediments for all Regions in 1989.

Aromatic Hydrocarbons In Sediments.

The concentrations of the sum of all aromatic hydrocarbons analytes (TOT PAH) from sediments collected in 1989 did not differ significantly from those sampled in previous years (Figure 8). The highest concentrations from 1989 were at the East Harrison Bay, West Harrison Bay and Kuparuk River areas (regions 4, 5 and 3 respectively, Figure 9). The sediments from these regions were also enriched in fines and TOC. Year to year variability in hydrocarbon concentrations are largely due to differences in various transport processes such as riverine transport and shoreline erosion.

While there was variability between stations and regions in the concentration of PAHs, the composition of the sediments was again fairly uniform in all regions. The PAH composition of Beaufort Sea sediments was characterized by a dominance of C2 and C3 alkyl homologue versus parent compounds (Figure 10) and a dominance of two and three ringed aromatic compounds (naphthalenes and phenanthrenes) over those with four and five rings (Figure 11) suggesting petrogenic rather than a pyrogenic source for the PAHs. The one four ring PAH compound found in abundance Beaufort Sea sediments is perylene, which is biogenic and/or diagenic in origin (Boehm et al, 1987).

Given the high background of fossil aromatic compounds in Beaufort Sea sediments, monitoring for incremental additions of PAHs from drilling activity is very difficult. Aromatic hydrocarbons, particularly the detailed aspects of the parent-alkyl homologue assemblages, as well as the diagnostic ratios play a key role in the environmental monitoring strategy. Ratios of total naphthalenes to total phenanthrenes (N/P), and total phenanthrenes to total dibenzothiophenes (P/D), as well as the ratios of individual parent and alkyl homologue compounds (C_0N/C_0P, C_1N/C_1P, etc.) can be used to detect changes in the hydrocarbon chemistry that otherwise would be masked. Furthermore, Prudhoe Bay crude oil has been characterized for the PAH alkyl homologue composition.

The ratios of N/P and P/D are presented for all four years in Table 1, along with the value for Prudhoe Bay crude oil. Values for N/P were high in all regions reflecting the high naphthalene sediment concentrations in this area. Values of the ratio were larger in 1989 for regions 2,4 and 6. P/D, which is low in Prudhoe Bay crude oil, showed no clear yearly trend over the four years of sampling. P/D ratios in the sediment are much higher than the value of the crude oil. Thus, there is no strong evidence of this crude oil in sediments, as reflected by the aromatic composition of the sediments, and by the diagnostic ratio parameters.

Endicott Development Island

The composition of the sediments from within the Endicott Development Island region (Region 8) were examined more closely, because of the significant drilling and production activity in that region. Station to station variability was apparent. The greatest concentration of total PAHs were found at 8A and 8E, which are to the north and east of the development island (Figure 12). Values for TOT were also highest at these stations. When TOT and PAH concentrations were normalized to TOC, these stations remained prominent, although station 8F, north of 8E had the highest PAH/TOC value (Figure 13). Stations with the highest concentrations of these normalized parameters are located slightly to the northwest and east of the development island while stations due west are clearly lower in concentration. Since the main current flow is to the west in this area, it is possible that construction of the causeway has caused an settling area on its eastern edge. The ratios LALK/TALK and pristane/phytane showed no evidence of a consistent trend, including any evidence of a gradient away from the development area. Likewise, careful comparison of the ratios of N/P and P/D, as well as the ratios of the individual alkyl homologues (i.e., C1P/C1D, C2P/C2D, etc.) showed no clear or consistent trend.

Finally, there was only slight evidence of pyrogenic inputs of PAHs in any of the regions. This finding can be seen when the ratio of the sum of the 4 and 5 ringed PAH compounds (minus the digenetic compound perylene) to the sum of the two and three ring compounds is taken. This ratio indicates that between 9 and 15% of the PAHs were of an obvious pyrogenic nature.

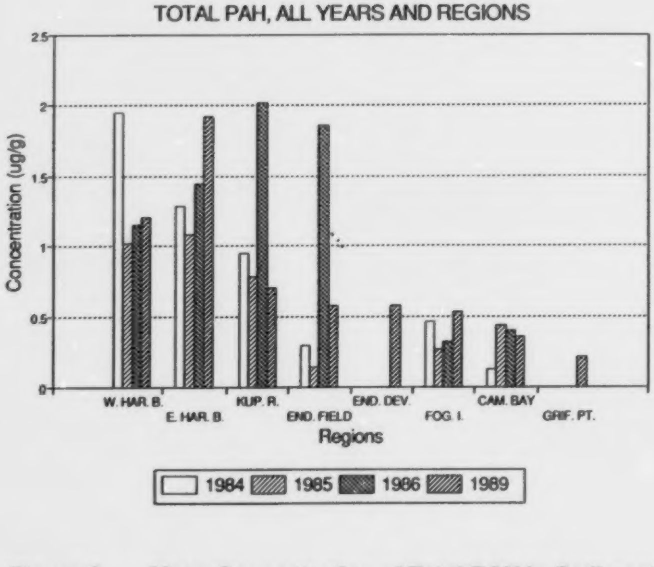


Figure 8 **Mean Concentration of Total PAH in Sediments for All Four Years in All Study Regions.**

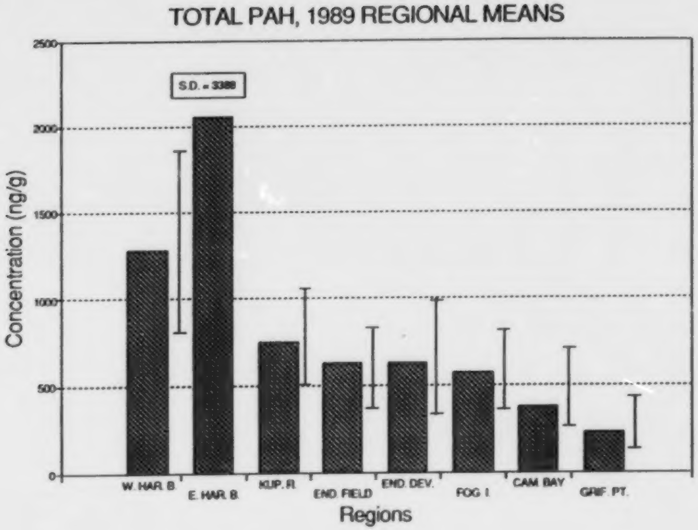


Figure 9 Mean Concentration of Total PAH for All Regions in 1989. Error Bars Represent the Standard Deviation (±.5 SD).

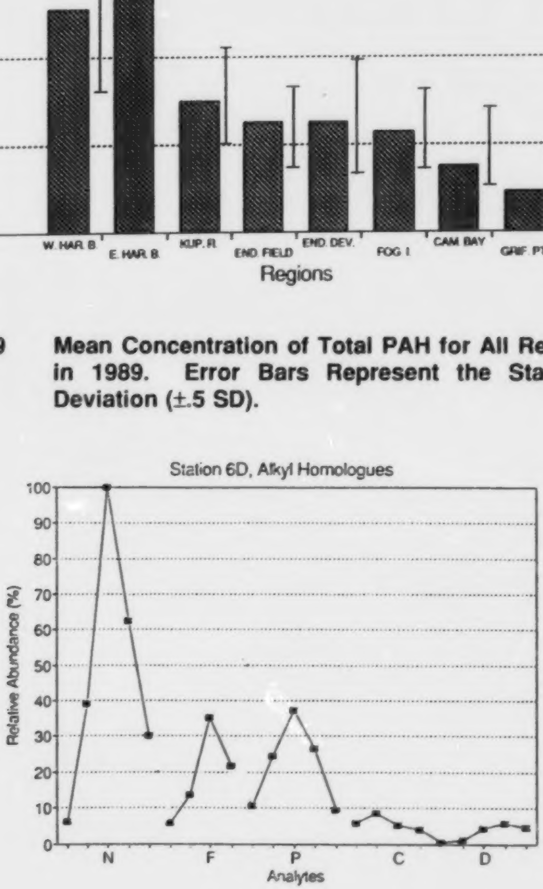


Figure 10 Representative Alkyl Homologue Distributions for 1989 Sediments. N = Naphthalenes, F = Fluorenes, P = Phenanthrenes, C = Chrysenes, D = Dibenzothiophenes.

Table 5.8. **Regional Mean Values of N/P and P/D in Sediments for All Four Years**

	1984			1985	
Region	N/P	P/D	Region	N/P	P/D
1	0.48	13.07	1	1.15	8.79
2	0.91	6.29	2	1.22	10.48
3	0.92	6	3	1.38	5.18
4	1.04	4.83	4	1.67	5.1
5	1.34	6.47	5	1.61	5.58
6	0.73	4.82	6	1.04	7.85

	1986			1989	
Region	N/P	P/D	Region	N/P	P/D
1	1.05	8.22	1	1.76	21.13
2	1.17	5.35	2	1.69	7.58
3	1.37	4.1	3	1.19	7.18
4	1.78	4.54	4	2.47	8.02
5	1.78	4.57	5	1.66	7.19
6	1.15	4.4	6	2.13	6.33
			7	1.12	9.62
			8	1.71	6.44

	N/P	P/D
Prudhoe Bay Crude Oil	3.0	1.2

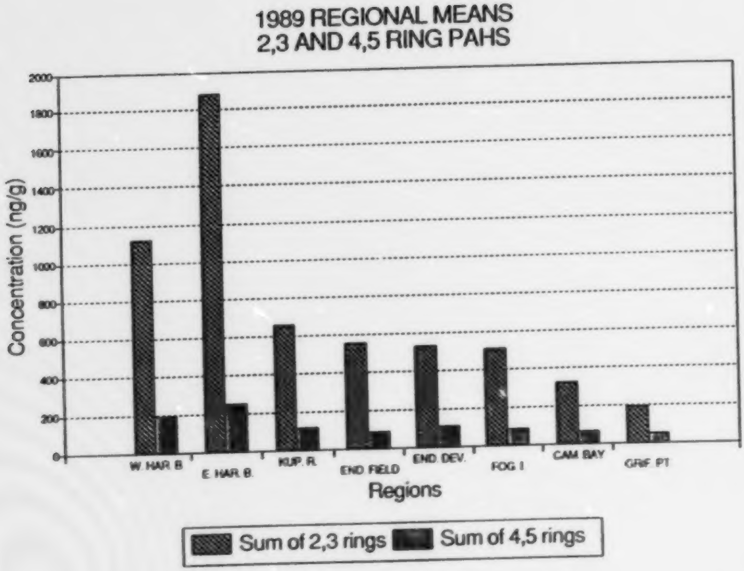


Figure 11 Mean Concentration of 2,3 Ring PAHs and 4,5 Ring PAHs in Sediments for All Regions in 1989.

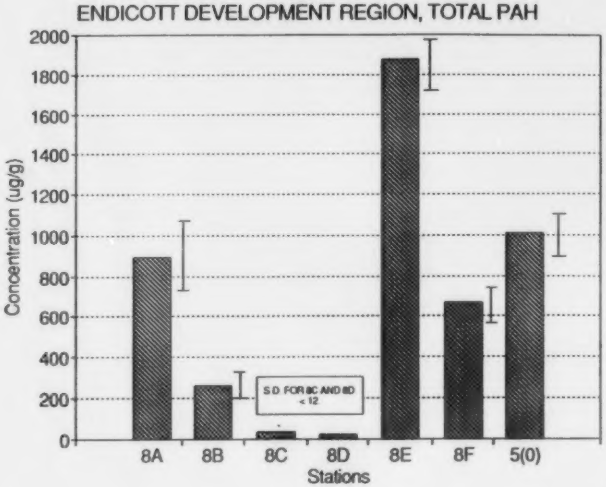


Figure 12 Mean Concentrations of Total PAHs in Sediments from Stations in the Endicott Development Island Region. Error Bars Represent the Standard Deviation (±.5 SD).

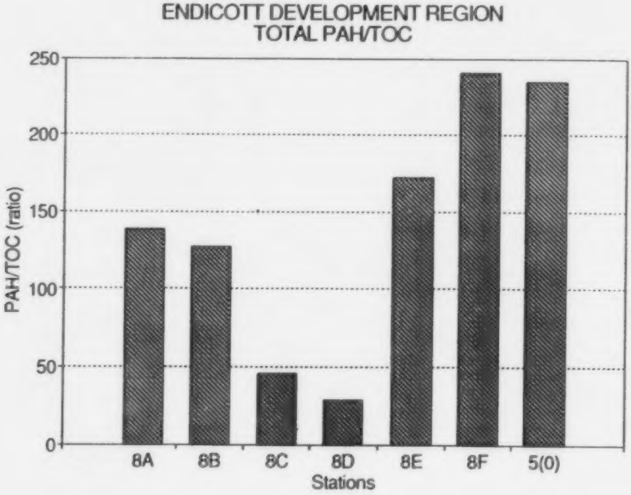


Figure 13 Mean Concentrations of Total PAH Normalized to TOC at Endicott Development Island Stations.

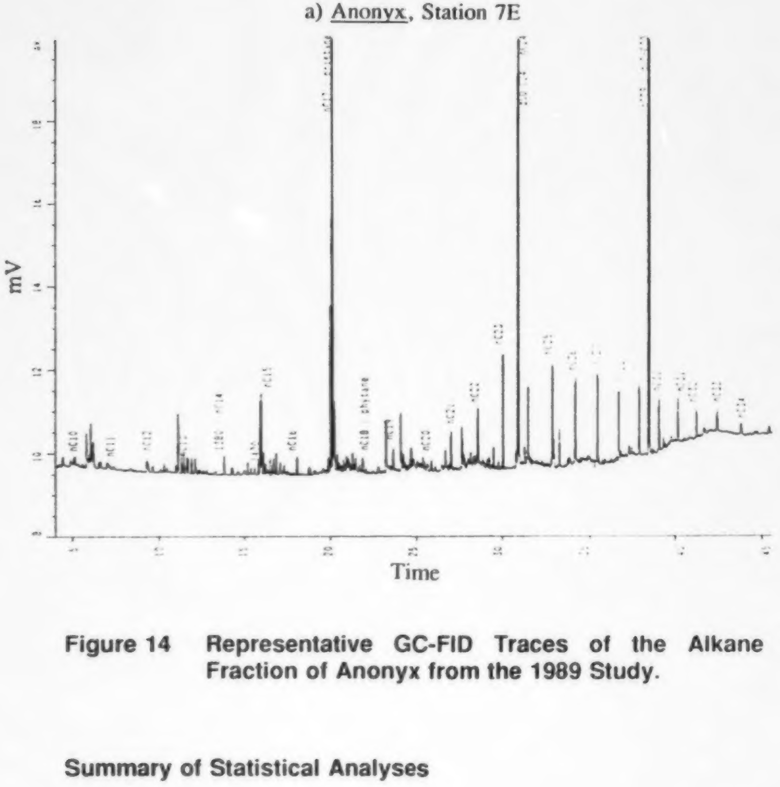
Hydrocarbons in Tissues.

Organisms collected from the Beaufort Sea represented two feeding types. Those that feed from the water column (filter feeders) acquire anthropogenic contaminants from the water column, such as the bivalves Astarte and Cyrtodaria. Those that reside at the sediment-water interface, such as the deposit feeding bivalves Macoma and Portlandia, and the amphipod Anonyx, acquire pollutants by processing sediment and/or detritus on the ocean floor.

The aromatic and saturated hydrocarbon composition of the tissues from these organisms was investigated and discussed in detail in Boehm et al., 1987. The main focus of the current study was to determine whether any significant increases in tissue concentrations had occurred in the three year hiatus of the Beaufort Sea Monitoring Program (1986-1989), as the result of increased oil drilling and exploration.

A representative GCFID trace showing the saturated hydrocarbon composition of the organisms sampled in 1989 is presented in Figure 14. Pristane was present at trace levels in all species, although it was a major component in Anonyx. Phytane was observed in trace levels in all organisms. Influence of sedimentary hydrocarbons, primarily plant wax alkanes from terrestrial sources was observed, at various concentrations, as a pattern of normal chain alkanes from nC21 to nC34 with a distinct odd to even preference. A distinguishing feature of GC/FID traces of Anonyx was small clusters of partially resolved saturated hydrocarbons in the lower (nC10-nC20) boiling point range and a small range unresolved complex mixture (UCM) of compounds in the nC27 to nC34 range, possibly of microbial origin. These features of Anonyx were also noted in Boehm et al., 1987.

Levels of aromatic hydrocarbons in tissues were generally low and near the limit of detection for many of the individual analytes. In most cases, the most abundant PAH compounds were the naphthalenes, most likely due to the high sediment concentrations of naphthalenes, which has already been discussed. Boehm et al., 1987, noted the low tissue concentrations of aromatics, in spite of an abundance of PAHs in the sediments. Dibenzothiophene compounds, which are abundant in Prudhoe Bay crude oil, were absent in all but one bivalve sample. Also, N/P ratios did not show a consistent trend over time for any species



a) Anonyx, Station 7E

Figure 14 **Representative GC-FID Traces of the Alkane Fraction of Anonyx from the 1989 Study.**

Summary of Statistical Analyses

Statistical analyses were performed on hydrocarbon sediment concentrations. The total number of observations in the data set was 462 with 99 variables. Analysis of variance, the main statistical test used for hypothesis testing, was performed on log transformed data to conform with other analyses developed in previous reports. Results from the analysis were back transformed to geometric means and relative standard deviations, as described in Boehm et al., 1987.

Analysis of variance was performed on sediments to test for the presence of trends over time and space and to address the following null hypotheses:

- Ho1: There will be no change in sediment concentrations of selected hydrocarbons.

- Ho2: Changes in concentrations of selected hydrocarbons in sediments are not related to OCS oil and gas development activity.

Several diagnostic parameters and the summed hydrocarbon parameters TOT PAH and TOT were analyzed, using a fixed effects analysis of variance. The interaction of station versus time was treated as the error term. The probability, expressed as the probability (Pr) that the actual result of the ANOVA was greater than the calculated F value ($Pr > F$) was determined for several factors. The model value looked at the differences between stations for all years. TOC was treated as a covariate for all ratios and summed values, that is variability due to changes in sediment TOC content were accounted for. Change in TOC was not found to be a significant interaction effect ($P < 0.05$) for any variables. Significant differences between years (year effect) were seen for all diagnostic ratios and summed parameters, due in part to the sensitivity of the test and the large number of degrees of freedom. Significant station-to-station differences ($p < 0.05$) were seen for pristane/phytane, P/D, N/P, TOT, and TOT PAH, but not for LALK/TALK.

However, the main question being addressed is whether the pattern of change of regional values in 1989 was different than during years 1984 - 1986, suggesting a perturbation beyond random variability. To test for this a class called year 4 was introduced into the fixed effects model, which tested for a change in regional patterns between years 1-3 and year 4. Differences were found to be significant for TOT, TOT PAH and N/P. The difference between the TOT measurements was due, in part to analytical differences between laboratories, as discussed in section 4.4.2. While the differences seen in the other observations are probably real, there is no convincing evidence, based upon the chemical analysis of sediments, that these differences were due to oil and gas exploration and activity as evidenced by the lack of significant changes in the diagnostic ratios, therefore Ho2 is not rejected. Results of this analysis proved no significant differences for the diagnostic ratios, LALK/TALK, PRIS/PHYT or P/D.

In summary, while there appeared to be some degree of correlation between hydrocarbon and metal parameters, consistent trends that can be related to drilling activities were difficult to discern.

Conclusions

The findings of this study indicate that the sampling and analytical designs, the selection of analytes and chemical diagnostics are appropriate for the future detection of oil-derived pollutant inputs to the region. The use of geochemical ratios are critical for detecting anthropogenic inputs of hydrocarbons in an area with high naturally-occuring hydrocarbon concentrations in the sediments. The results to date indicate not only the consistency between the 1984-1987 and 1989 data sets, but also support the conclusions that activities such oil and gas exploration and production have had no significant input of pollutants to the area's sediment or benthic biota.

References

Boehm, P.D., E. Crecelius, J.M. Neff, C.E. Tuckfield, and M. Steinhauer. 1987. Final Report on Beaufort Sea Monitoring Program: Analysis of Trace Metals and Hydrocarbons from Outer Continental Shelf (OCS) Activities. Submitted to the Minerals Management Service, Alaska OCS Region, Anchorage, AK.

BIOREMEDIATION AND TUNDRA RESTORATION AFTER AN OIL SPILL IN THE KUPARUK OILFIELD, ALASKA, 1990

by

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ABSTRACT

In August 1989, an estimated 300-600 bbl (12,600-25,200 gal) of crude oil and produced water leaked from a valve in a production pipeline from Drill Site 2-U in the Kuparuk Oilfield, contaminating 1.4 acres of arctic coastal tundra. A site assessment revealed that most of the oil was confined to the tundra surface. Remediation techniques for the site were selected to achieve a balance between rapid decontamination of the site and restoration of the original ecosystem.

Initial cleanup focused on containment and recovery of oil. Before freeze up in 1989, oil was removed by flushing, raking, and swabbing. In April 1990, the frozen surface layer (1-3 in. depth) within the area of heavy oiling was scraped with heavy equipment to remove oil, while avoiding destruction of subsurface plant material. During summer 1990, aerobic and anaerobic biodegradation of the remaining oil was promoted by controlling water levels and surface moisture, by fertilization, and by aeration.

Periodic sampling for total petroleum hydrocarbons (TPH) revealed that mean oil concentrations at the soil surface (0-2 in. depth) in August 1990 (996 ppm, n = 10) had decreased by 63% relative to values from 12 September 1989 (2,715 ppm). When mean TPH values from August 1990 were compared to values from June 1990 (15,522 ppm), a reduction in TPH of 94% had occurred. At subsurface depths (7-9 in. depth), mean TPH concentrations decreased 90% from September 1989 (165 ppm) to August 1990 (16 ppm).

Cleanup activity caused substantial damage to vegetation at the tundra surface, but the preservation of subsurface roots and stems allowed partial recovery within a year of the spill. After the first summer, the cover of vascular plants in the treated area (10.6%) was 21% of that on an adjacent unaffected area (50.3%), due to prevalent resprouting of damaged vegetation.

INTRODUCTION

One year after crude oil and produced water leaked onto 1.4 acres of arctic coastal tundra near Drill Site 2-U in the Kuparuk Oilfield of northern Alaska, substantial progress has been made toward reducing the level of hydrocarbon contamination and restoring the original structure and function of the affected tundra ecosystem. The techniques used at Drill Site 2-U were selected to achieve a balance between more rapid, but disruptive techniques, for decontaminating the tundra (such as excavation) and those that best promote the natural recovery of the original ecosystem. This paper briefly describes the spill, techniques used to clean up oil and promote natural recovery, and monitoring of hydrocarbon contamination and plant cover.

The spill resulted from a leaking valve in a 16-inch production pipeline carrying crude oil, natural gas, and water from Drill Site 2-U to a processing facility. The spill was detected on 25 August 1989 and was estimated to have been leaking for two to three days. During that period, an estimated 300-600 bbl (12,600 to 25,200 gal) were lost onto the tundra. The leaking oil pooled beneath the valve, then flowed down a narrow swale, through a few polygon troughs at the toe of a slope, and finally formed into pools on a flat area at the edge of a drained lake basin. This movement resulted in a mosaic of oiled and unaffected areas, depending on the micro-relief. Assessment of oil infiltration revealed that most of the oil was confined to the surface of the water-saturated tundra, although minor amounts of water-soluble oil fractions had mixed into the subsurface.

ARCO Alaska, Inc. (operators of the Kuparuk Oilfield) and its contractors initiated cleanup efforts immediately after the spill was detected. Additional winter cleanup was conducted in April 1990 and bioremediation treatments were applied during summer 1990 to degrade the remaining hydrocarbons. To ensure adequate cleanup and restoration, ARCO Alaska, Inc. and the Alaska Department of Environmental Conservation agreed on a set of quantitative standards for ecosystem recovery that must be met within three years; otherwise, further cleanup, including excavation, may be required. The three criteria for cleanup success are as follows: 1) the mean percentage of vascular plant cover within the affected area shall be equal to or greater than 30% of the plant cover in an adjacent unaffected area; 2) the mean concentration of measured total petroleum hydrocarbons (TPH) in the affected area shall not exceed 500 ppm; and 3) the effects of thermal degradation of the permafrost shall be limited to a few polygon trough formations similar to those in natural tundra. This spill is the first occasion for which quantitative standards have been set for clean up of oil spills in Alaska.

CLEANUP AND BIOREMEDIATION

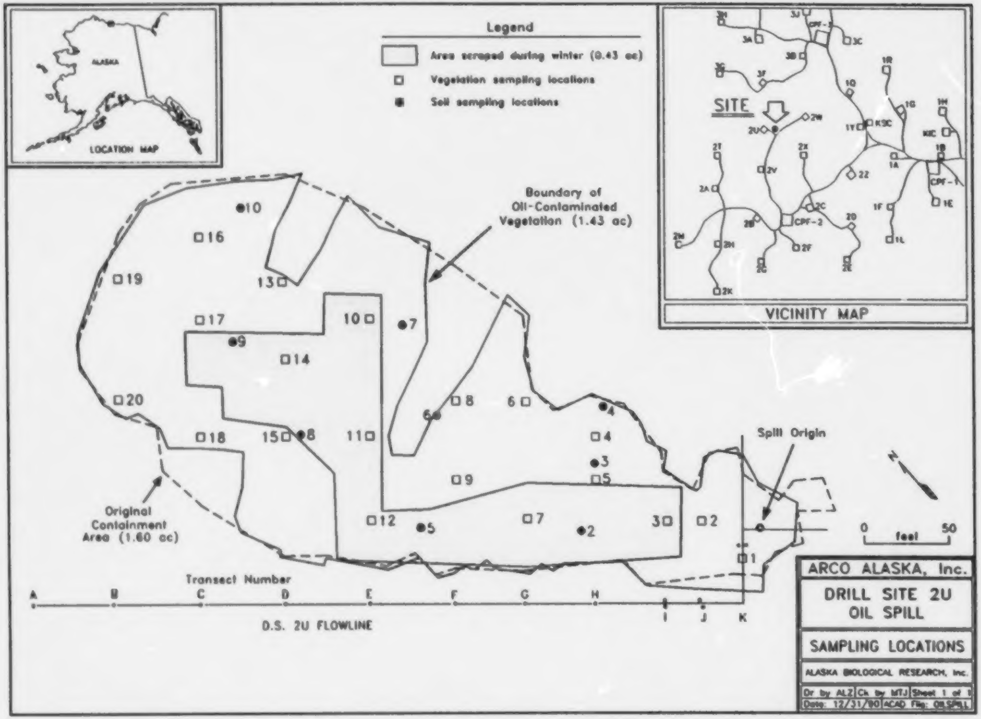
Initial cleanup efforts focused on containment and recovery of the liquid crude oil. Sandbags and absorbent material were piled around the perimeter to contain the spread of oil. Oil was removed by flushing the surface with warm water and then vacuuming up the oil and water mixture. Heavily contaminated vegetation was raked off and oily spots were swabbed with absorbent material. Boardwalks were laid down to minimize trampling of vegetation. The site was then allowed to freeze in the fall of 1989 to await additional cleanup activities during late winter in 1990. The volume of oil remaining was estimated at 18-50 bbl.

In April 1990, the oily moss mat and plant litter were scraped off the frozen surface in the zone of heaviest contamination (Figure 1) using a scarifier mounted on a grader. Heavily contaminated troughs were scraped with the tip of the grader blade. The dislodged material then was removed with a front-end loader. After breakup, the few heavily oiled patches remaining in the spill area were removed by hand raking. To promote both aerobic and anaerobic biodegradation of the remaining oil, the site then was heavily fertilized once in mid-June and once in mid-July 1990. The surface was aerated in mid-July with a rotating bar equipped with 8-in.-long tines. The microbial environment was enhanced further by controlling surface moisture and groundwater levels within the containment area. A small sandbag dike was established upslope from the spill to divert water away from the site and the area was sprayed occasionally with water to keep the surface moist. Anaerobic biodegradation in water-saturated subsurface soils was promoted by adding ammonium nitrate. Finally, a snow fence was set up around the area to keep out wildlife and a wildlife guard was posted.

MONITORING OF TUNDRA RESTORATION

VEGETATION

Cleanup activities caused substantial damage to vegetation at the tundra surface, but preservation of subsurface roots and stems has allowed partial recovery. By the end of the first growing season after the spill, vascular plant cover in the oiled area (10.6%) was 21% of that on an adjacent unaffected area (50.3%)(Figure 2). In places where the surface was not scraped during cleanup, many sedges and willows readily survived the oiling. In heavily scraped areas, both sedges and willows vigorously resprouted, although deep scraping had penetrated the root zone and prevented resprouting in several patches. The plants that resprouted are expected to continue establishing new shoots in the scraped areas, hastening recovery of the original vegetation as the surviving plants spread.


LOCATION MAP
ALASKA
Legend
Area scraped during winter (0.43 ac)
Vegetation sampling locations
Soil sampling locations
VICINITY MAP
SITE
Boundary of Oil-Contaminated Vegetation (1.43 ac)
Original Containment Area (1.60 ac)
Spill Origin
Transect Number
D.S. 2U FLOWLINE
A
B
C
D
E
F
G
H
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feet
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ARCO ALASKA, Inc.
DRILL SITE 2U OIL SPILL
SAMPLING LOCATIONS
ALASKA BIOLOGICAL RESEARCH, Inc.
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Figure 1. Layout of 2U oil spill, Kuparuk Oilfield, Alaska, 1990.

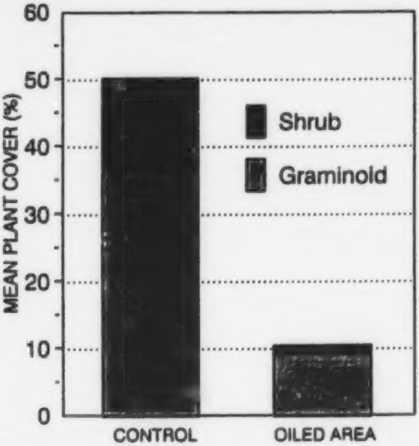

Figure 2. Mean plant cover (%) in the treated and control areas, Drill Site 2-U oil spill, Kuparuk Oilfield, Alaska.

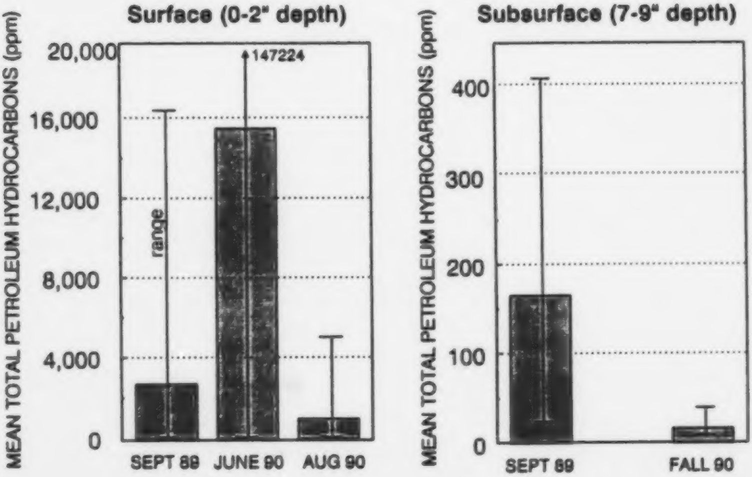

Figure 3. Mean concentrations of total petroleum hydrocarbons (wet weight) in surface and subsurface soils, Drill Site 2-U oil spill, Kuparuk Oilfield, Alaska, 1989-1990.

HYDROCARBON CONCENTRATIONS

Sampling for TPH (EPA method 418.1) revealed that mean oil concentrations at the soil surface (top 2 in.) on 24 August 1990 (996 ppm, n = 10) had decreased by 63% relative to values from 12 September 1989 (2,715 ppm). When mean TPH values from August 1990 were compared to values obtained on 29 June 1990 (15,522 ppm), a reduction in TPH of 94% had occurred. However, the June results were skewed by one very high value (147,224 ppm) that substantially affected the mean (Figure 3). When data were examined to determine how frequently samples were under the regulatory threshold of 500 ppm, a more consistent trend was found. In September 1989, 5 of 9 samples exceeded 500 ppm; in June 1990, 4 of 10 samples exceeded 500 ppm; and in August 1990, 2 of 10 samples exceeded this value.

Samples also were taken from the middle of the active layer (7-9 in. depth) to determine the degree of subsurface degradation of hydrocarbons. At subsurface depths, mean TPH concentrations had decreased 90% from 165 ppm in September 1989 to 16 ppm in August 1990. All subsurface values in August 1990 (6-36 ppm) were within the range of TPH values found in unaffected soil (0-44 ppm).

This rapid reduction in petroleum hydrocarbons can be attributed to both photo-oxidation from solar radiation, which helped break down larger hydrocarbon molecules, and microbial degradation. By the end of the summer 1990, oil at the surface was solid and friable, leaving only a slight oily residue when rubbed.

THAW SETTLEMENT

Although raking and scraping removed much of the oil, the resulting surface disruption has initiated thermal erosion along some of the ice wedges. To prevent further subsidence in these areas, the troughs and holes were filled with organic soil, which will provide both insulation and a good growing medium for vegetation.

CONCLUSION

Flushing with water, raking, and winter scraping helped remove gross levels of oil contamination, and bioremediation is rapidly reducing the remaining petroleum hydrocarbons. During the first summer following the spill, the rates of hydrocarbon degradation and plant growth were greater than expected; hydrocarbon levels and plant cover are already close to meeting the quantitative standards established for recovery. The remaining degraded oil residue no longer presents a hazard to wildlife through incidental contact with feathers or fur. With additional bioremediation and restoration efforts, this site should recover to a stage at which ecological structure and functions are similar to its prespill condition.

BODY WEIGHT DEVELOPMENT AND THERMOREGULATION OF OIL-CONTAMINATED GREY SEAL PUPS (*HALICHOERUS GRYPUS*) AT THE FROAN ARCHIPELAGO, NORWAY.

by

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Abstract

The Froan nature reserve off central Norway and less than 100 km from Haltenbanken where offshore oil activity soon will be developing, is the main breeding area for grey seals (*Halichoerus grypus*) in Norway. During September and October about 300 pregnant grey seal females, representing nearly 50% of the reproductive females in the Norwegian stock, congregate in the area to give birth to their single pups. Since 1985, surveys have shown that 30 - 50% of all pups born at Froan become oil contaminated during their first month of life. The aim of this study was to clarify the degree to which pups are contaminated by oil, and to examine whether this oil affects the normal weight development and energetics (thermal balance) of grey seal pups. Of a total of 269 grey seal pups born at Froan in 1990, 141 individuals (52.6 %) were oil-contaminated. Chemical analyses of oil samples from the pupping grounds shows that the contamination most likely originated from the coastal ship traffic and/or offshore oil activity in the North Sea. The majority of the oiled pups (78.7 %) were contaminated by only a few small spots of oil. Nevertheless, 7.1 %, of the oiled pups had more than 25% of their body surface covered by oil. The risk for a pup to become oiled increases with increasing age. However, the oil may disappear from the fur when the white lanugo fur is moulted. This study indicates that the oil contamination experienced by the grey seal pups in the Froan breeding area has no effect on their normal body weight development.

Introduction

The Froan nature reserve (64° 10'N, 09° 20'E), off the coast of central Norway and less than 100 km from Haltenbanken where offshore oil activity is to be initiated within a few years, is the main breeding area for grey seals (*Halichoerus grypus*) in Norway. During September and October about 300 pregnant grey seal females, representing nearly 50% of the reproductive females in the Norwegian stock (Wiig *et al.* 1990) which is estimated to be 3200 individuals (Wiig 1986), congregate in the area to give birth to their single pups. Since 1985, surveys have shown that 30 - 50% of all pups born become oil contaminated during their first month of life (Ekker *et al.* 1991).

Harmful effects of heavy oil contamination of seals have been reported (Davis and Anderson 1976, Geraci and Smith 1976, Kooyman *et al.* 1977, Parsons *et al.* 1980), but in general, adult phocoid seals seem to show a high tolerance to external oiling (Engelhardt 1985). However, few studies have focused on the effects of external oiling of seal pups. Newborn seal pups lack the well-developed blubber layer and usually rely on their white lanugo (prenatal fur) and metabolic activity for thermal balance (Øritsland and Ronald 1973, Blix *et al.* 1979). Oiling of the lanugo of grey seal pups may therefore cause similar thermal effects as shown in sea otters and in fur seals (Costa and Kooyman 1982, Kooyman *et al.* 1977). The purpose of the present study was to document the degree to which the fur of grey seal pups at Froan is covered by oil and to examine the question of whether or not fur-oiling results in a stunted growth rate due to increased heat loss and a resultant increase in energy expenditure in order to remain normothermic.

Materials and methods

The study was carried out from September 20th. until November 6th., 1990 in the Froan nature reserve, approximately 30 km off the coast of central Norway. The Froan archipelago covers 400 km^2 and is formed by hundreds of small islands and skerries.

Field studies

An inflatable boat was used for transportation and the activity involved landing on all islands and skerries used by grey seals. After being born the pups stay ashore for approximately four weeks and are therefore easy to catch and handle. At the first encounter each pup was tagged for later identification with a numbered plastic tag (Rototag) in one hind flipper. All pups were weighed, sexed and age classified according to the age groups described in Table 1. The degree to which the fur of each animal was contaminated by oil was classified into one of the five categories described in Table 2. Upon later encounters with tagged pups, the procedures of weighing, age-, sex-, and oil-fouling classification were repeated.

Table 1. Morphological characteristics used for classifying grey seal pups into different age groups (after Radford *et al.* 1978, Kovacs and Lavigne 1986).

Stage 0	Newborn, fresh blood on or near pup. Age 0 - 24 hours.
Stage I	Body contour thin, neck well defined, skin in loose folds round body. Yellow tint to pelage. Umbiculus present, pink or brown, not dried (variable character). Age 1 - 4 days.
Stage II	Outline smoother with neck still recognizable, but no loose folds on body. Pelage white. Umbiculus not present. Age 5 - 8 days.
Stage III	Outline rounded to barrel-shaped. Neck indistinguishable. Pelage white to light grey. Lanugo intact except for slight loss in the facial region toward the end of the stage. Age 9 - 18 days.
Stage IV	Outline as stage III. Lanugo being shed, exposing the juvenile pelage. (These pups are either weaned or approaching weaning). Age 19 - 25 days.
Stage V	Moulted pup, less than ~5% of the body surface still retaining lanugo. Age > 25 days.

Physiological studies

For measurements of oxygen-consumption and body temperature ten pups were brought to a laboratory which was set up on a pier in an abandoned fishing village (Nordbuan) in the central part of the nature reserve. Electric power for the equipment was provided by portable generator.

Prior to each experiment the oxygen analyzer (Sevomex OA-250) was calibrated against dry atmospheric air (20.95% O_2). The experiment were performed between 10:00 - 18:00 in an open-circuit system (Depocas and Hart 1957). The pups were placed in a dark respiration chamber (200 L) and air was pumped through the system at a rate of 37 - 82 L min^{-1}, ensuring an oxygen extraction of less than 1%. A fraction of the effluent air was pumped into the oxygen analyzer for continous determination of the O_2-content. The oxygen consumption (VO_2) was calculated using standard equations (Withers 1977) and corrected to STPD conditions.

Table 2. Classification of the oil-contamination on the pelage of grey seal pups.

Category 0	No detectable oil-contamination of the pelage.
Category 1	Light contamination; few small spots (1 - 2 cm in diameter).
Category 2	Medium contamination; several small spots, or few larger oilspots (5 - 10 cm in diameter).
Category 3	Heavily oiled; more than ca. 25 % of the body surface covered with oil.
Category 4	Totally covered with oil (body surface totally covered by oil).

The deep body temperature of the pups (T_B) was measured 15 - 30 cm inside the rectum, and the air (T_A) and water (T_W) temperatures in the chamber were measured continually during the experiments using copper-constantan thermocouples.

The heat loss from the pups (thermal conductance [C_T]) was estimated according to the equation: $C_T = VO_2 / (T_B - T_{A/W})$.

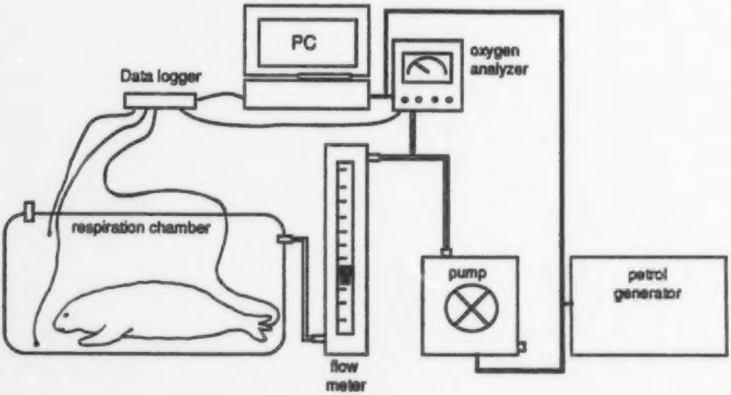

Figure 1. Experimental set-up for measuring metabolic rate (oxygen consumption) and body temperature on grey seal pups.

Studies were first conducted on each pup during rest and exposure to air. To elucidate whether external oiling facilitates heat loss when pups are at sea, each pup was immediately afterwards exposed to water. In the latter experiments the respiration chamber was filled with 70L of seawater, allowing the pup to float freely. In the air experiments, the air temperature was held constant within ± 0.5 °C during each experiment. In the water experiments, the temperature in the water and air were identical, and held constant within ±0.5 °C during each experiment.

The output signal from the oxygen analyzer, the T_B, T_A and T_W were registered at 30-second intervals during the entire experiment using a Grant Squirrel datalogger. After each experiment the data were transferred to a portable PC (Toshiba 1200) for later treatment. Representative values of O_2-consumption, T_B and the thermal conductance of each animal were taken for two 10-minute periods, one in air and one in water, when the pups were resting inside the chamber. Prior to these ten-minute periods, the pups had been allowed to acclimate to the experimental conditions for at least 90 minutes.

In the physiological studies, an additional age group, II+, was introduced. This stage is intermediate to group II and III, and is defined as: Outline rounded. Neck distinguishable when the pup lies stretched out on the ground. Lanugo intact. Age 7 - 8 days.

Student's t-test was used for inter-group statistical comparison, and a p-value less than 0.05 was considered significant.

Results

The weather conditions allowed 27 days in the field out of a total of 48 days which were spent in the area. During the field period a total number of 269 grey seal pups were tagged. Of these 121 were males (45 %) and 145 were females (53.9 %). Three pups were not sexed. In addition to this, 264 encounters of already tagged pups were made. Of all tagged pups, 128 individuals (47.4%) were never found with oil-contaminated pelages, while 141 individuals (52.6%) were found with oil on their pelage (Table 3). Furthermore, 71 (48.6%) of all females were oiled, whereas 67 (55.4%) of all male pups were contaminated at some time during their pup-period.

According to table 3, 78.7% of the contaminated pups were contaminated by a few small oilspots (Category 1), whereas 14.2% of the oiled pups were categorized as medium contaminated, having several small oil spots, or a few larger oil spots on their pelage (Category 2). Further, 4.3% of the oiled pups were categorized as heavily oiled, with more than 25% of their body surface covered by oil (Category 3), and finally, 2.8% of all oiled individuals were totally covered by oil (Category 4).

The data show that among the pups in age group I, 76.7% of all the pups were clean (Fig. 2). From age group I to age group II, the percentage of contaminated pups increased from 23.3% to 47.4% . The greatest percentage of oil-contaminated pups were found in age group III, where 51.7% of all pups were oiled. Among pups in age group IV and V, the percentage of oiled animals declined to 37.3% and 23.3%, respectively.

Table 3. Number of grey seal pups, and the percentage of total, in each of the five different oil-categories.

Category	Total#	%of total	Males	%of males	females	%of females
0	128	47.4	54	44.6	74	50.7
1	111	41.1	53	43.8	55	37.7
2	20	7.4	9	7.4	11	7.5
3	6	2.2	5	4.1	1	0.7
4	4	1.5	-	-	4	2.7

In all five age groups, the majority of the oiled pups were lightly oiled (oil-category 1). The highest percentage (10.8%) of moderately oiled specimens (oil-category 2) was found among pups in age group II, whereas heavily oiled individuals and individuals totally covered by oil seemed to be randomly distributed among the age stages (Fig. 2).

Weight development
The body weight was registered once or more in 103 clean pups and in 92 oiled pups. An easy method to assess possible effects of external oiling on body weight development is to compare the body weights of clean and oiled pups in each age group. Figure 3 showes the body weight of clean and oiled grey seal pups as a function of their age stage. The data is based only on weight measurements registered at our first contact with each pup, thus, each pup is counted only once. Except for the pups belonging to group II, there were no statistical differences in the body weight of clean and oiled grey seal pups. The body weight of clean pups belonging to age group II, 20.3 kg (SD = 3.0, n = 55), was significantly lower ($t = -3.572$, $p < 0.001$, df = 77) than the body weight of oiled pups belonging to the same age group, 23.7 kg (SD = 5.4, n = 24).

The body weight was recorded in twenty-one pups which had been oiled for more than eight days, and was 40.5 kg (SD = 8.6, n = 6), 44.5 (SD = 10.2, n = 11) and 37.0 (SD = 4.2, n = 2), in these pups which belonged to age group III, IV and V, respectively. These values are not significantly different from that found among clean pups belonging to the same age groups.

The weight development of grey seal pups can be divided into two distinctly different periods: The growth period in age group I - III when the pups are suckling, and the weight loss period during age Stage III - V when the pups are weaned and may have started fasting. Multiple weightings of 67 pups (30 females and 37 males) allowed us to estimate the body weight change during the suckling period, and during/after weaning. We assumed a linear increase in weight during suckling period, and a linear weight loss during/after weaning. The results are listed in Table 4 and show that there was no significant difference in the rate at which clean and oiled animals gained weight during the suckling period. In the weaning period (Stage III-V), there is a tendency ($t = 5.31$, $p = 0.108$, df = 24) toward a difference in the weight development of oiled male pups as compared to clean male pups. However, as the sample-size is very small, the data are regarded as inconclusive.

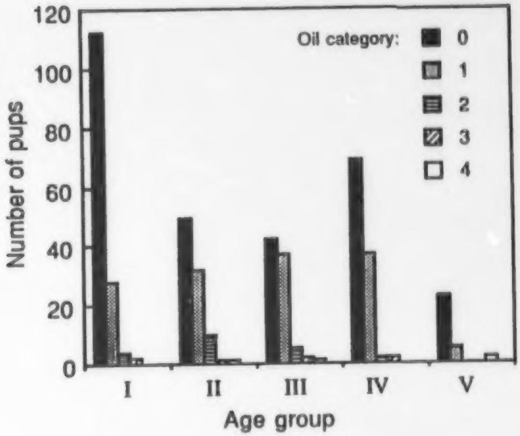

Figure 2. Number of grey seal pups in each contamination-category at each of the five age stages. Due to multiple observations some pups are listed several times, but only once at each stage. The total number of cases is therefore larger than the number of animals tagged.

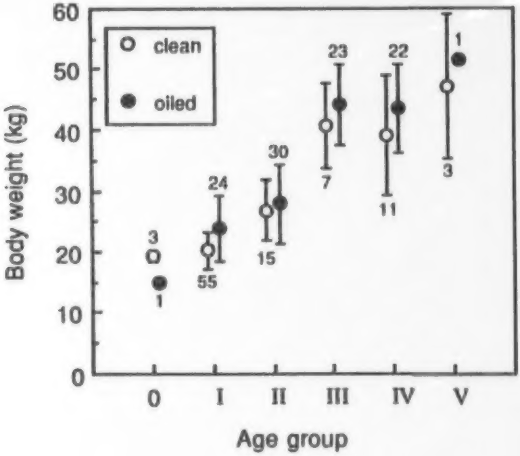

Figure 3. Weight of clean and oiled grey seal pups as a function of age group.

Table 4. Mean ±SD daily weight change (kg) for clean and oil-contaminated male and female grey seal pups during the suckling and fasting period.

Males				Females		
Group	Clean	Oiled	sign.	Clean	Oiled	sign.
Suckling	2.0±0.6 (10)	1.3±1.4 (10)	NS	1.6±1.4 (6)	1.5±1.4 (13)	NS
Weaned	0.4±1.3 (6)	-0.6±0.4 (20)	p = 0.108	-0.2±0.7 (11)	-0.3±1.0 (11)	NS

Thermoregulation

Oxygen consumption and body temperature were measured in ten grey seal pups, six clean pups, three pups which only had small spots of oil on their fur (Category 1), and in one pup which was found completely covered with oil (Category 4). Due to the low number of animals, it should be noted that the thermoregulatory part of the study is considered to be of value as a pilot-study only.

The oxygen consumption of the pups during exposure to air and water is depicted in Figure 4, and the result indicates that there seems to be no difference in the metabolic rate (MR) of clean and oiled pups. Even the pup which was completely covered with oil, had an oxygen consumption similar to that of a clean pup belonging to the same age group. Thus, as other growing homeotherms, grey seal pups follow an energy consumption pattern where the MR is highest during their most intensive growth period (during stage I and II), and the MR is lowered when the weight increase ceases in stage IV and V when the pups are weaned or fasting.

Water immersion did not seem to increase the energy expenditure of oiled pups as compared to normal pups (Fig. 4). The MR of pups during water exposure was higher than during air exposure only during age Stage I. In Stage II throughout V, the MR of the pups were similar during air and water exposure.

The body temperature of clean pups in air and water, was 37.3 °C (SD = 0.1, n = 6) and 37.5 °C (SD = 0.4, n = 4), respectively. During air exposure, the T_B of the lightly oiled pups was 37.3 °C (SD = 0.3, n = 3), within the range registered in clean pups. During water-exposure, the T_B was only measured in two lightly oiled pups, and was 37.5 and 37.0 °C. These values are within the range found in the clean pups during water exposure. The T_B of the pup completely covered by oil was 37.5 °C both in air and in water, within the range found in clean pups. Thus, the body temperature of the pups did not seem to be affected by oil on their pelage. The average T_B was 37.3 °C (SD = 0.2, n = 10) and 37.4 °C (SD = 0.3, n = 7), in air and water, respectively, and did not vary with the age of the pups.

In air, the thermal conductance was estimated in all ten pups. However, due to lack of T_B-measurements, C_T could only be estimated in seven animals during water exposure: 4 clean pups, 2 lightly oiled pups, and in the one pup totally covered with oil. The results are depicted in figure 5 and show that there seems to be no difference in the C_T of clean and oiled pups. Also the pup which was completely covered with oil had a heat loss similar to that of a clean pup belonging to the same age group. Thus, in general, grey seal pups seem to have a high heat loss during Stages I and II, whereas it is reduced when they reach Stage V.

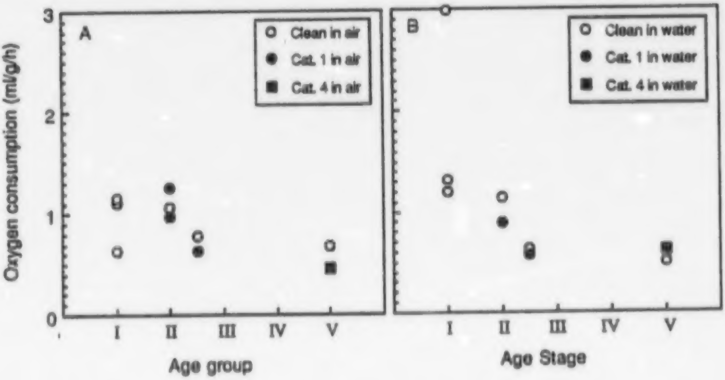

Figure 5. Metabolic rate of grey seal pups during exposure to air (A), and during exposure to water (B).

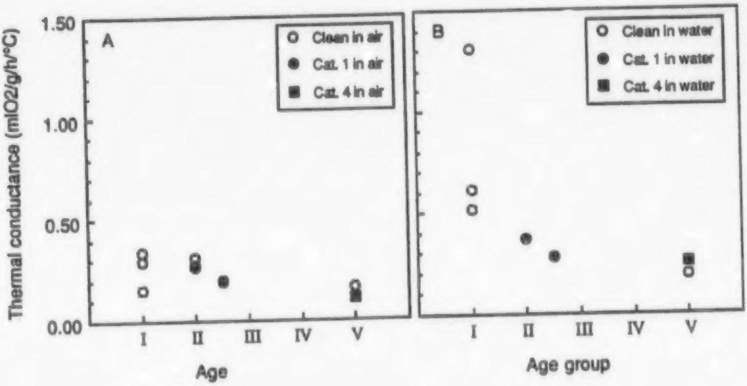

Figure 5. Thermal conductance of grey seal pups during exposure to air (A), and during exposure to water (B).

Discussion

This study shows that in the 1990 breeding season, approximately 53% of all grey seal pups born at the Froan archipelago were oil-fouled at some time during their first month of life. Most of the oiled pups were contaminated by only small spots of oil. The study also shows that the oil-contamination experienced by grey seal pups at Froan did not affect their body weight development during the postnatal period.

The proximate source of contamination of the pups is beached oil which forms tarry encrustations of highly viscous oil on shore. When the pups are in contact with these spots their body heat softens the oil which then adheres to the fur. Furthermore, as oil is often found just above the high tide level, frequent passing through this zone will increase the risk of getting oil-fouled. The risk of becoming oiled therefore increases with increasing age.

To reveal the sources of the oil pollution at Froan, seven samples of relatively fresh beached oil from different locations in the breeding area were collected for chemical analysis. The chemical composition of three of the samples indicates that these are crude oils, whereas the four other oil-samples seems to be a heavy bunker oil (Johnsen 1990). The sources for the oil pollution at Froan therefore seems to be bunker oil from coastal ship traffic and crude oil originating either from coastal ship traffic or from offshore oil activity in the North Sea.

Since the Froan archipelago is located within the coastal current running northwards along the Norwegian coast, just east of the Haltenbank area (Sætre *et al.* 1979), the archipelago forms a funnel for marine pollution originating from regular ship traffic as well as from the offshore oil activities at Haltenbanken and in the North Sea. The rate of oiled grey seal pups at Froan may therefore serve as an environmental monitoring parameter which reflects the oil-pollution status along the Norwegian coast. The ratio of grey seal pups at Froan which become oil-fouled during their first month of life seems to have increased from about 0.3 in the mid-eighties to about 0.5 in 1989 and 1990 (Table. 6). It is possible that this is due to a worsening of the chronic oil pollution along the Norwegian coast. However, it is also possible that an increased awareness among biologists tagging pups at Froan has led to better procedures for documenting oiled pups, which in turn results in a constantly increasing ratio of oiled grey seal pups.

This study shows that the proportion of oiled pups increases with increasing age until the pups reach age group III. In age groups IV and V, the proportion of oiled pups decreased, presumably because the oil disappears as the white lanugo fur is being molted. One should however be aware that the ratio of oiled pups in age group IV and V may have been underestimated because oilspots are more difficult to detect on the dark adult-like pelage.

Table 6. Total number of grey seal pups tagged and the number and percentage of total found oil contaminated between 1985 and 1990. The data from 1985 - 1989 are given by Ekker *et al.* (1991).

Year	Tagged	Oiled	%age oiled
1985*	192	64	33.3
1986*	215	84	39.1
1987*	116	32	27.6
1988*	201	82	40.8
1989*	231	117	50.6
1990	269	141	52.6

*data from Ekker *et al.* (1991)

Although it is well documented that grey seal pups at Froan are oil-fouled (Ekker *et al.* 1991), no report has been made on the degree to which their pelage is covered by oil. This study reveals that in 1990 the the majority of the oiled pups (78.7 %) were contaminated by only a few small oilspots. Nevertheless, we found six pups with approximately 30% of their body surface covered by oil, and four pups which were totally covered by oil.

Weight development

An easy method to test the hypothesis that the fur-oiling experienced by the grey seal pups at Froan stunts their body weight development, is to compare the body weights which were registered in clean and oiled pups at our first contact with each individual. In such a test, each weighed pup counts only once, thus reducing the bias that may be caused by multiple weighings of a selected part of the pup-population. Except for the pups belonging to age group II, there were no statistical differences in the body weight of oiled and cleaned pups. Among pups in age group II, the oiled individuals had a significantly higher body weight as compared to clean individuals. The data on which this conclusion is based does not, however, not indicate for how long a period the oiled pups have been contaminated. This uncertainty can be eliminated by comparing the growth rate of clean and oiled pups. There seems to be a tendency that during the weaning/fasting period oiled male pups lose weight at a higher rate than do clean male pups. It should however be noted that body weight changes were registered in only six clean male pups, and the observed high rate of weight loss in oiled male pups may therefore merely be due to a small sample size. When pooling data for two sexes, there was no significant difference in the growth rate of clean and oiled pups in either the growth period (stage 0 - III), nor in the weaning/fasting period (stage III - V).

Previously, Davis and Anderson (1976) have reported that oil contaminated grey seal pups may have a restrained morphological development, and that their peak weight at weaning was reduced. Grey seal pups reach their peak weight at weaning during age stage III. Our data show that there is no significant difference between the body weight of clean and oiled pups in age group III ($t = -1.147$, $p = 0.261$, $df = 28$). This indicates that the fur-oiling encountered by grey seal pups at Froan has no effect on their peak weight at weaning.

Ekker *et al.* (1991) estimated growth rate in 21 grey seal pups (12 clean and 9 oiled pups) during the 1989 breeding season. Although they found a 30% lower growth rate in oiled pups as compared to clean pups, this difference was not statistically significant ($0.05 < p < 0.1$). Although the growth rate of the 33 clean pups in the present study was somewhat higher compared to that of the 54 oiled pups, the difference was not statistically significant. Thus, the fur-oiling encountered by grey seal pups at Froan does not seem to have any effect on the growth rate.

The lack of effect of the fur-oiling experienced by grey seal pups at Froan on body weight development may be due to the fact that the majority of the oiled pups (78.7 %), were only lightly contaminated by a few small oilspots. It is therefore interesting to take a closer look at the weighed pups which belonged to oil-category 3 and 4. In general these oiled pups have body weights which are within the range of that measured in clean pups belonging to the same age groups. It may also be of interest to elucidate the fate of one pup, #E9592, which was observed several times. This pup was weighed twice while it was completely oiled, and its rate of body weight loss during fasting was estimated to 0.6 kg day^{-1}, a value which is within the range estimated for clean pups (Table 4). The present study also indicates that the body weight of pups which had been oiled for more than eight days did not differ from that of clean pups of the same age group.

Thermoregulation

The air and water temperatures which the grey seal pups were exposed to during the thermoregulatory studies, 11 - 15 °C, are in the upper range of what free-living pups at Froan may encounter during autumn. It should be noted that thermoregulatory studies only were performed on four oiled pups and on six clean pups, and this part of the study is considered to be of value only as a pilot-study. The results indicate that during exposure to moderate air and water temperatures, neither body temperature, oxygen consumption nor heat loss of oiled pups differs from that of clean pups. This is also the case for the individual, pup #E9592, which was completely covered by oil. The field observations reveal the life history of this pup: It was caught unpolluted first on September 24th.(Stage II), and then again on September 30th (Stage III). On October 13th. the pup was found completely covered with a thin layer of oil (Category 4, Stage IV), and was still covered by oil when it was brought in for physiological studies on October 23rd (Stage V). Thus, even though this pup had been heavily oiled for at least 10 days, no effect was observed on oxygen consumption (energy expenditure), body temperature or heat loss. As previously shown, its daily weight loss after weaning was similar to that of clean pups.

In polar bears (*Ursus maritimus*), rats (*Rattus norvegicus*) and in common eiders (*Somateria molissima*), external oiling has been demonstrated to initiate fever (or hypothermia), presumably due to ingestion of oil during grooming- or preening-activity (Hurst *et al.* 1982, Haim *et al.* 1984, Jenssen 1989, Jenssen and Ekker 1991). The lack of effect of external oiling on the body temperature of grey seal pups is presumably due to the fact that oiled pups do not ingest oil from their pelage, simply because they do not groom their pelage.

Oiling of the pelage of fur seals and sea otters, and oiling of the plumage of seabirds causes increases in thermal conductance and a resultant increase in metabolic rate (Kooyman *et al.* 1977, Costa and Kooyman 1982, Jenssen and Ekker 1989, 1991). The mechanism responsible for this is the disruption of the water-repellent structure of the fur or plumage by the oil, causing water to substitute the insulating layer of air in the fur or plumage. Since the thermal conductivity and heat capacity of water is much higher than that of air, the heat loss from externally oiled otters, fur seals and birds increases. The lack of effect of fur-oiling on thermal conductance and metabolic rate of grey seal pups is due to the fact that the subcutanous layer of blubber (and not an air filled fur) is responsible for thermal insulation in phocid seals. However, according to van Haaften (1973) heat loss from oiled phocid seals can be facilitated by cutaneous vasodillation caused by inflammatory effects of the oil. This does not, however, seem to have been the case with the pups which were examined in this study.

With respect to possible toxic effects of the fur-oiling, the normal body temperature in the oiled pups indicate that they do not ingest the oil on their fur. However, the oil may still be transported into the animal via the peripheral blood circulation. Thus, in order to obtain a full view of the impact of oil-pollution on grey seal pups at Froan nature reserve, future studies should also include toxicological studies.

In summary, 52.6 % of the grey seal pups born at Froan in 1990 were oil-contaminated. Chemical analyses of oil samples from the pupping ground show that these most likely originated from coastal ship traffic and/or offshore oil activity in the North Sea. The majority of the oiled pups (78.7 %) were contaminated by only a few small spots of oil. Nevertheless, 7.1 %, or ten individuals had more than 25 % of their body surface covered by oil. The chances for a pup to become oiled increases with increasing age. However, the oil may disappear from the fur when the white lanugo fur is moulted. This study indicates that the oil contamination experienced by the grey seal pups in the Froan breeding area has no effect on their normal body weight development.

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ERRATA:

BODY WEIGHT DEVELOPMENT AND THERMOREGULATION OF OIL-CONTAMINATED GREY SEAL PUPS (*HALICHOERUS GRYPUS*) AT THE FROAN ARCHIPELAGO, NORWAY

by

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We regret the following corrections in our paper. All page numbers refers to the page number of the paper:

Page 5, paragraph 2, line 1: The sentence *" The body weight was registered once or more in 103 clean pups and in 92 oiled pups."* should read *" The body weight was registered once or more in 94 clean pups and in 101 oiled pups."*

Page 5, paragraph 2, line 7 and 8: *"...group II,..."* should read *"... group I,..."*.

Page 9, paragraph 3, line 4: *" from the offshore activities at Haltenbanken and in the North Sea."* should read *"...from the offshore activities in the North Sea."*

Page 10, paragraph 1, line 6 and 7: *"age group II"* should read *"age group I"*.

Page 10, paragraph 3, line 6: *"... statistically significant."* should read *"...statistically significant (Table 4)."*

OIL-SENSITIVE BIOMARKER STUDIES OF FISH FROM ARCTIC CANADA

by

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Abstract

Several field and laboratory studies on marine and freshwater fish have shown elevations in liver mixed-function oxidase (MFO) enzyme activities following exposures to petroleum oils or to a small number of other environmental contaminants (PCBs, chlorinated dioxins/furans, PAHs). Application of these techniques in an arctic context is limited by lack of background data on ranges in enzymatic activities to be expected in arctic animals in the absence of a pollution incident. We are have conducted experimental oil enzyme induction experiments with several northern species (burbot, char, harp seals) and confirmed the sensitivity of the animals using two activity measurements, aryl hydrocarbon hydroxylase (AHH), and ethoxyresorufin-O-deethylase (EROD). We have also sampled several populations of fish in the Mackenzie and other drainages (burbot, whitefishes) to determine ranges in activities. These data, when plotted on maps, extend from the Beaufort coast to northwestern Ontario; they allow simple detection of a population showing abnormal activity. Alternatively the data can show the absence of effect in cases of suspected contamination of fisheries. For example, enzyme data have allowed us to argue against petroleum as the direct cause of complaints about the quality of fish in the lower Mackenzie river. In another instance, they identified a different case of contamination (chlorinated dioxins and furans) in the upper Fraser drainage well in advance of its detection by residue chemistry.

Introduction

During the mid-1980s complaints were received from DENE communities, Fort Good Hope in particular, regarding the quality of fish from the lower Mackenzie river drainage. These complaints followed the expansion of oil production at Norman Wells, and resulted in local suspicion that the cause of the problems was oil leakage from Norman Wells. We investigated this possibility (Lockhart *et al.* 1987; 1989) and concluded that, while the complaints were legitimate, the cause was probably not oil pollution from Norman Wells. Liver microsomal enzymatic activities have been shown to be one of the most reliable indicators of oil pollution in fish (Payne, 1976), although they respond to a small number of contaminants other than oil, notably PCBs, chlorinated dioxins and furans, and PAHs (probably the active components of petroleum oils). There is virtually no information on the enzymatic activities of arctic fish, although the few data on the subject suggest that arctic species respond in the same way as temperate species (Lockhart *et al.*, 1987; 1989; Thomas et al., 1989).

In this study we describe some aspects of the MFO activities found in arctic species of fish. Some aspects of the burbot data have been presented recently by Lockhart and Metner (1991).

Methods

Fish were captured from several locations throughout western and northern Canada, generally by gill nets (whitefish species) and baited hooks (burbot). Each collection was assigned a lot number which applied to all the fish taken at that time and location (Table 1).

Table 1. Collections of burbot for MFO enzyme activity determinations.

Lot No.	Date	Location	Lat	Long	Females	Males
3	4/85	Fort Good Hope	66 16	128 37	6	10
10	2/86	Lake Winnipeg	51 09	96 40	22	2
15	9/86	Fort Good Hope	66 16	128 37	17	10
16	10/86	Fort McPherson	67 29	134 50	2	3
27	8/87	Southern Indian Lake	56 47	98 56	9	1
29	8/87	Missi Falls	56 47	98 56	7	1
30	9/86	N.W. Ontario, Lake 625	49 45	93 48	10	6
46	3/88	Fort Good Hope	66 16	128 37	2	8
72	9/88	Fort Smith	60 01	111 55	1	0
89	12/88	Fort Smith	60 01	111 55	8	7
90	3/89	N.W. Ontario, Lake 625	49 45	93 48	9	2
97	12/89	Fort Smith	60 01	111 55	6	1
103	6/90	Thunder Bay	48 22	89 08	1	1

Upon removal from the water fish were kept chilled until livers were dissected and fast frozen on dry ice for shipment to Winnipeg. Where possible dissection was done immediately upon removal from the water, but in some instances dissection was delayed for up to 4 hours. Upon arrival in Winnipeg the samples were transferred to a freezer at -60°C until analyzed for catalytic activities. Preparation of microsomes and measures of both AHH and EROD activities were as described by Lockhart *et al.* (1989), adapted from published procedures (DePierre *et al.*, 1975; Van Cantfort *et al.*, 1977 for AHH; Pohl and Fouts, 1980 for EROD). Cytochrome P-450 spectra were recorded using essentially the procedures of Omura and Sato (1964a,b) with a single-bean Beckman DU-7 spectrophotometer.

Enzymatic activities were examined using a covariance analysis of SAS (Freund and Littell, 1981) under "PROC GLM", considering sex, weight, length and lot number (time and place of collection) to determine whether there were differences among collections that could not be explained by sex or size measures. When these differences were detected site comparisons were made using Duncan's multiple range test.

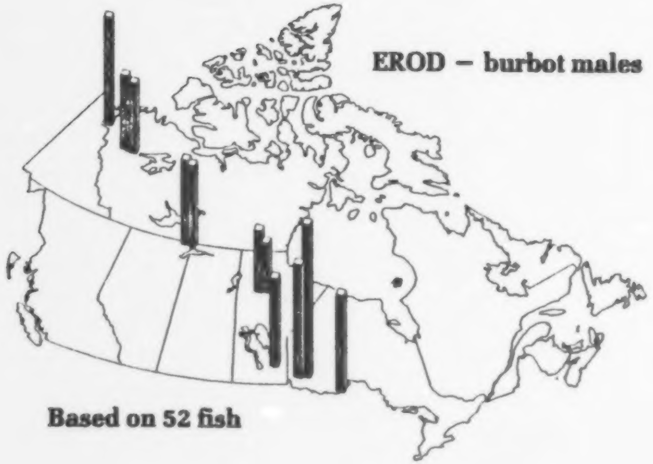
Results

Fish collections

Burbot collections are listed in Table 1 above. We obtained three collections from Fort Good Hope, two in late winter (April, 1985 and March, 1988) and one in late fall (Sept., 1986).

Burbot liver microsomal EROD

When the covariance model to describe (log of) EROD activity included sex, log weight, log length and lot number, type III sums of squares indicated that sex influenced activity greatly ($p<.0001$); log weight, log length, and lot number all fell short of the criterion of 5 % significance. The model had an R-square value of 0.405. This analysis implies that there were not large differences in EROD activity due to the location of collection after the influences of sex and size of the fish were discounted. Burbot EROD activities for each sex are shown in map form in Figure 1. Inspection of these maps shows no consistent trend toward high EROD activities in the three samples of from Fort Good Hope. There was one relatively high value (0.028 nmol per mg protein per min) in the females from that community, consisting of two fish taken late in March, 1988; the two individual values were 0.009 and 0.047, hence the high mean value was due to a single individual. The other two samples of females from Fort Good Hope were both taken in April, 1985 and September, 1986, and neither gave unusually high activities. The actual EROD activities in the three collections from Fort Good Hope are shown in Table 2.


EROD – burbot males
Based on 52 fish

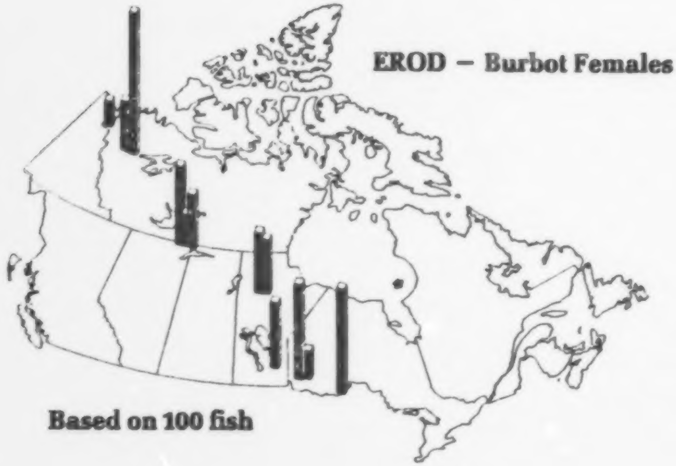

EROD – Burbot Females
Based on 100 fish

Figure 1. Maps showing relative liver microsomal EROD activities in male and female burbot from several locations over a time period from April, 1985, to June, 1990.

Table 2. Mean lengths (mm), weights (g) and liver microsomal EROD levels (nmol per mg protein per min at 25°C) in burbot from Fort Good Hope, N.W.T.

Lot	Date	Sex	N	Length	Weight	EROD
3	April '85	F	6	710±143	2268±1439	.0097±.0059
3	April '85	M	10	651±93	1510±639	.0191±.0102
15	Sept. '86	F	17	806±125	3270±1464	.0074±.0042
15	Sept. '86	M	10	754±119	2520±1132	.0119±.0048
46	March '88	F	2	623±86	1364±491	.0280±.0268
46	March '88	M	8	706±84	1963±732	.0181±.0071

Norman Wells oil induces EROD activity strongly in fish (Lockhart *et al.* 1989), although the threshold levels required for induction have not been determined. If oil from Norman Wells were moving downstream in sufficient quantity to reach threshold induction levels we might expect to see somewhat higher EROD values in the fish at Fort Good Hope than at other areas where there were no sources of oil (N.W. Ontario Lake 625). Failure to find such a difference implies that there was not enough oil reaching the fish to exceed threshold EROD induction levels.

The large differences due to the sex of the fish is of considerable practical importance in trying to apply MFO techniques to environmental monitoring. The overall mean EROD value for the 100 females was 0.0106±0.0088 nmol mg prot^{-1} min^{-1} at 25°C, while that for males was almost twice as great at 0.0199±0.0098. Within females the activity was related to the degree of sexual maturity as reflected in the weight of the developing egg mass. We weighed ovaries from 49 females and fish with larger ovarian weights had lower EROD activities (Figure 2). Previous studies with lake trout from southern Canada have noted decreased MFO activity near spawning time (Luxon *et al.*, 1987). For the 31 males for which we obtained weights of testes, there was not a significant relationship between the EROD activity and gonad weight.

Burbot liver microsomal AHH

We obtained AHH activity measurements on 148 burbot from thirteen collections. The covariance model applied to (log of) AHH activities again included sex, log length, log weight and lot number. The model identified sex and lot with significant effects on activity ($p<0.01$ for sex and $p<0.0001$ for lot) indicating that different collections differed in activity even after effects of sex and fish size were removed. The model had an R-square value of 0.627. The overall mean for AHH in males was 0.0201, nmol mg prot^{-1} min^{-1}, again almost twice that of 0.0099 for females; previous studies have reported sex differences in AHH activity in other species (Walton *et al.*, The actual values for the Fort Good Hope and Fort McPherson burbot are listed in Table 3.

The AHH activities for each sex are shown in maps (Figure 3) and two of the three samples of females from Fort Good Hope are higher than those from southern locations. The Peel river (Fort McPherson) sample was also high for females, but it contained only two very large individuals. The high values for females from Fort Good Hope were from the two collections made late in winter when the river was covered with ice, and would be consistent with oil reaching moving under ice during winter. However, only one of these same collections (April, 1985) showed high values for EROD in females (Table 2), and none had high values for males (Figure 1).

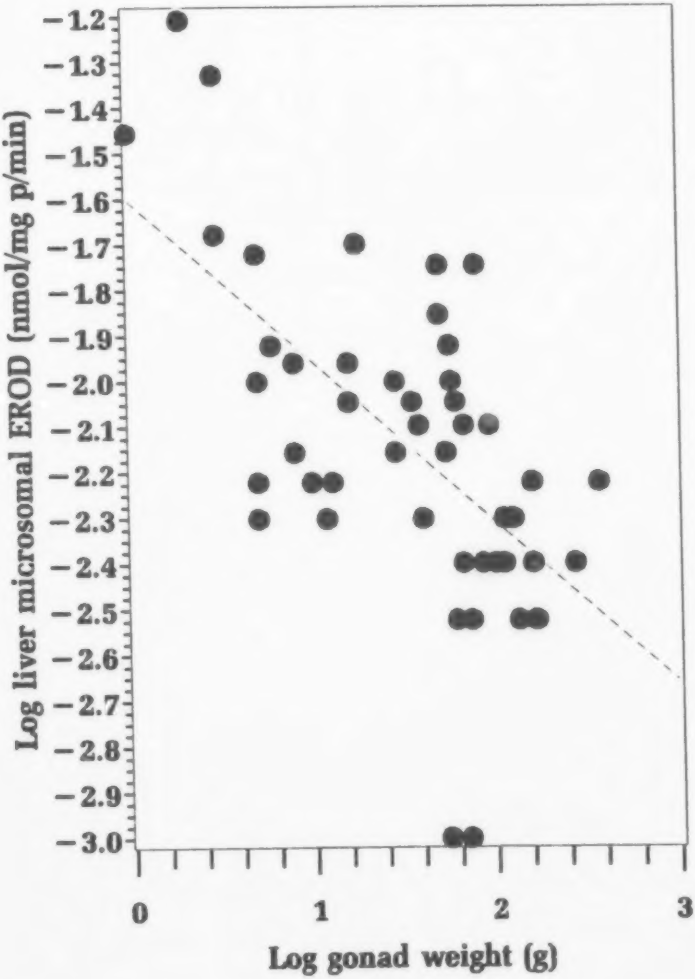


Figure 2. Relationship between weight of developing ovaries and liver microsomal EROD activity for female burbot.

Table 3. Mean lengths (mm), weights (g) and liver microsomal AHH levels (nmol per mg protein per min at 25°C) in burbot from Fort Good Hope, N.W.T. and Fort McPherson, N.W.T.

Lot	Date	Sex	N	Length	Weight	AHH
Fort Good Hope						
3	April '85	F	6	710±143	2268±1439	.0380±.0117
3	April '85	M	10	651±93	1510±639	.0520±.0197
15	Sept. '86	F	17	806±125	3270±1464	.0083±.0035
15	Sept. '86	M	10	754±119	2520±1132	.0081±.0061
46	March '88	F	2	623±86	1364±491	.0245±.0205
46	March '88	M	8	706±84	1963±732	.0171±.0085
Fort McPherson						
16	Oct. '86	F	2	964±118	6147±1841	.0075±.0007
16	Oct. '86	M	3	607±67	1952±644	.0253±.0064

Ovarian weights were taken for 49 females and, as was the case with EROD, these weights were correlated negatively with AHH activity; females with heavier ovaries had lower AHH activities. With males we obtained weights of testes for 31 individuals and a similar but somewhat stronger relationship was observed than for females, unlike the observation noted above for EROD in males.

Discussion

The enzymatic analyses reported here were prompted originally by the question of possible oil pollution from Norman Wells reaching fish taken in the domestic fishery at Fort Good Hope. The analyses suggested initially that there may have been some effect on the fish in April, 1985, when the first samples were collected because the AHH activities were high for both males (about 2.5-fold over grand mean) and females (about 3.8-fold over grand mean). EROD values, however, were not exceptional. If the AHH values were elevated due to oil intoxication, then we should expect to see that reflected in both AHH and EROD activities. In September, 1986, none of the enzymatic values were noteworthy, hence there is no suggestion of oil toxicology. In March, 1988, the EROD value for females was about 2.8 times the grand mean for females, but the high mean was for only two fish, one with a very high value. With AHH, again the females appeared high, about 2.5 times the grand mean, but again it was due to a sample of only two fish, one with a normal value and one with a high value. Overall there is not a consistent pattern of enzymatic activities to support the contention that the fish taken at Fort Good Hope were exposed to sufficient oil to result in enzyme induction. Rather, the data suggest the opposite interpretation; the hypothesis that oil has resulted in induction is falsified.

In a more general sense, the question of effects of oil on fish and marine mammal resources of the Mackenzie drainage are recurring with oil sand production in the Athabasca drainage, conventional oil and gas in several locations, and future production in the Mackenzie delta and nearshore Beaufort Sea. The data presented here, and companion data on other species, will help to recognize such effects if they occur, and will help to support or refute cause/effect arguments in cases of suspected effects.

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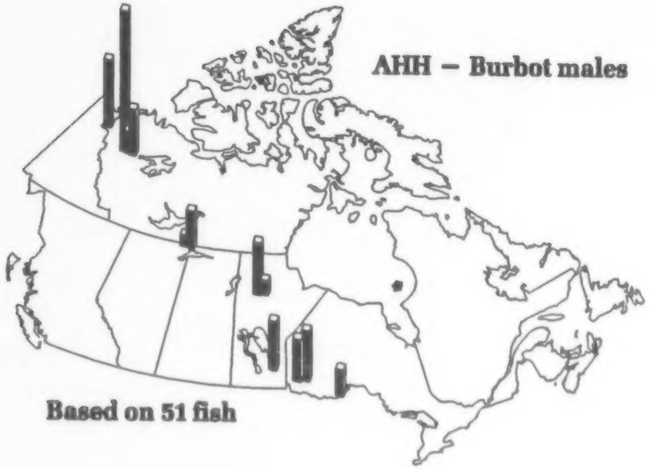
AHH – Burbot males
Based on 51 fish

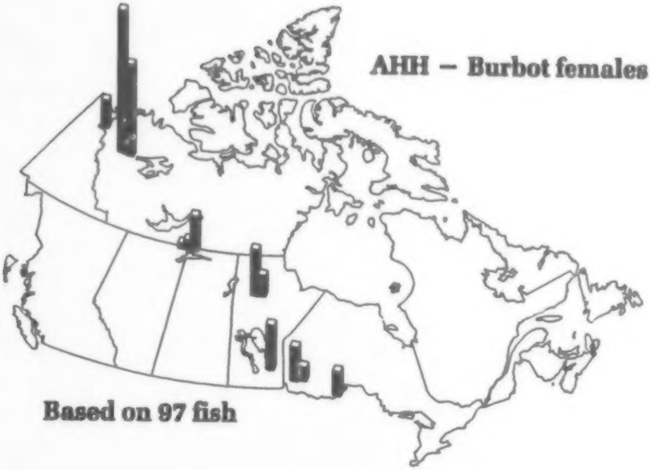
AHH – Burbot females
Based on 97 fish

Figure 3. Maps showing relative liver microsomal AHH activities in male and female burbot from several locations over a time period from April, 1985, to June, 1990.

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West Coast Oil Spills: British Columbia Initiatives

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Abstract

The Environmental Emergency Services Branch was created in 1990 in response to concerns about oil spills, such as the Nestucca and Exxon Valdez oil spills, and other emergencies which threatened the British Columbia environment. The Branch has developed a Provincial Marine Oil Spill Preparedness and Response Strategy for co-ordinated action with industry, the public and the federal government. As part of this strategy, it has undertaken several initiatives related to oil spills on the west coast of British Columbia. These initiatives are concerned with management and organization planning, and resource information and planning. They include preparation of the British Columbia Oil Spill Contingency Plan, the creation of Ministry of Environment Oil Spill Response Teams, mapping shoreline sensitivity and countermeasures, and developing computer inventories of personnel and equipment. An electronic Oil Spill Response Information System and a Coastal Oil Spill Auxiliary are also included in these initiatives.

Introduction

Following the Nestucca oil spill off the coast of Washington in December, 1988 and the Exxon Valdez spill in 1989 of 258, 000 barrels of oil in Prince William Sound, the British Columbia Government jointly initiated the States/BC Oil Spill Task Force study, as well as, the report to the Premier on Oil Transportation and Oil Spills (Anderson, 1989). The Task Force and the Anderson study objectives were to investigate ways and means of preventing oil spills, review oil spill response procedures, document and assess the mechanisms for handling compensation claims, and develop a coordinated contingency plan for preventing and responding to oil spills in the future.

The Report to the Premier on Oil Transportation and Oil Spills was released in December 1989 and the Final Report of the States/BC Oil Spill Task Force was presented in October 1990. There were several multi-jurisdictional recommendations in these reports that dealt with the following:

- Prevention issues such as vessel traffic and design, personnel, enforcement, regulations;
- Oil spill preparation including shoreline sensitivity mapping, onshore response and disposal issues, communications, resource inventories and research;
- Management and organizational issues such as public involvement, mutual aid, provincial/state contingency plans, training and response team structures; and
- Compensation issues including cost recovery, natural resource valuation, and insurance.

The Ministry of Environment in response to these studies has developed a comprehensive Provincial Marine Oil Spill Preparedness and Response Strategy for co-ordinated action with industry, the public and the federal government. As part of this strategy, the Environmental Emergency Services Branch has undertaken several initiatives related to oil spill management and organization planning, and resource information and planning. This paper reviews some of these initiatives.

Management and Organizational Planning Initiatives

Initiatives related to management and organizational planning include the creation of the Environmental Emergency Services Branch, the preparation of the British Columbia Oil Spill Contingency Plan, and the formation and training of the Ministry of Environment Oil Spill Response Teams.

The Environmental Emergency Services Branch is a new organization within the Ministry of Environment which was created in 1990. It is responsible for co-ordinating activities within the Ministry to enhance planning, preparedness and response for environmental emergencies. The Branch deals with natural and man-made emergencies including marine oil spills.

The Branch has been responsible for, and has recently completed, the British Columbia Marine Oil Spill Contingency Plan. The plan describes the Provincial response strategy (which changes from a regional team response for a small spill to a multi-teamed Provincial response during a large spill), outlines the Ministry and Response Teams notification procedures and contacts, defines the Response Teams structure and organization, details the roles of other Ministry Branches, and identifies supporting agencies and their roles and responsibilities.

The contingency plan is a working document for the Ministry Regional Response Teams. Three teams have been formed and include a Northcoast Team located in Smithers, a Vancouver Island Team in Nanaimo, and a Southcoast Team operating out of Surrey. The structure of each team is based on the Incident Command System (refer to Figure 1) which consists of five functional sections. These are:

- A Command Section consisting of an On-scene Commander and staff that is responsible for overall management of the incident either as a single or unified command with other jurisdictions.

- An Operations Section that has three units that undertakes shoreline protection (Protection Unit), removal and disposal of collective oil waste (Disposal Unit) and treatment and rescue of wildlife (Wildlife Rescue Unit).

- A Planning Section that has a Resource Assessment Unit and a Site Assessment Unit. The latter unit is a field unit responsible for mapping and assessing oil impacts and providing protection and cleanup recommendations. The Resource Assessment Unit determines shoreline protection and cleanup priorities, manages data collection, and provides factual spill information to the Command Section. The functions of this section are similar to the Government Interagency Committees and Shoreline Cleanup Assessment Teams (SCAT Teams) of the Valdez spill.

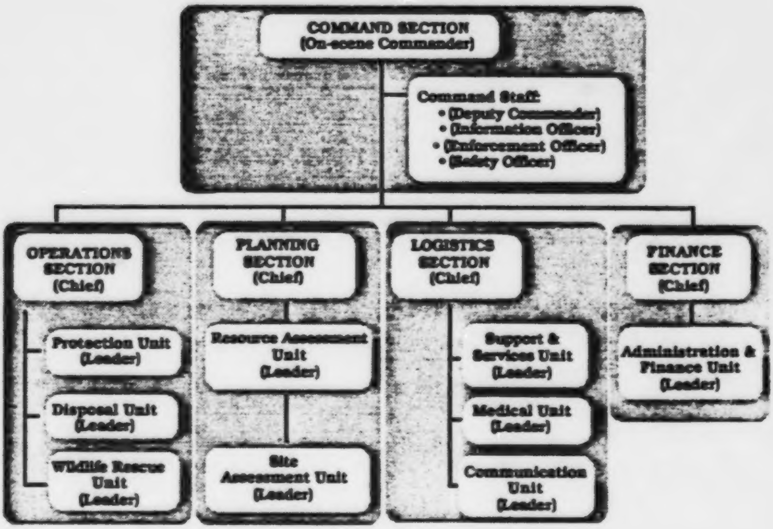
COMMAND SECTION
(On-scene Commander)
Command Staff:
• (Deputy Commander)
• (Information Officer)
• (Enforcement Officer)
• (Safety Officer)
OPERATIONS SECTION (Chief)
Protection Unit (Leader)
Disposal Unit (Leader)
Wildlife Rescue Unit (Leader)
PLANNING SECTION (Chief)
Resource Assessment Unit (Leader)
Site Assessment Unit (Leader)
LOGISTICS SECTION (Chief)
Support & Services Unit (Leader)
Medical Unit (Leader)
Communication Unit (Leader)
FINANCE SECTION (Chief)
Administration & Finance Unit (Leader)

Figure 1: BC Response Teams Incident Command System

- A Logistic Section consisting of three units that are responsible for providing support services related to transportation, equipment and facilities (Support and Services Unit), developing and maintaining communication systems (Communication Unit), and providing medical and first aid treatment (Medical Unit).

- A Finance Section responsible for providing financial and administrative support.

The Response Teams have been provided with some initial training related to shoreline protection and cleanup strategies and Team on-scene-commanders have participated in marine oil spill exercises. A B.C. Shoreline Protection and Cleanup Manual has also been prepared that provides decision diagrams on equipment selection and appropriate cleanup options for different shoreline types, and information related to equipment types, use and deployment (Cramer, M.A.; Owens, E.H.; Howes, D.E.; and Sergy, G.A. - these Proceedings). The purpose of the manual is to provide the teams with a reference document and field guide that will assist and promote effective and rapid shoreline protection and cleanup decisions during a spill event. The manual will also be used as a training document to upgrade existing response team members skills and to train new members.

Finally, the Ministry has spent about $400,000.00 to outfit approximately two hundred field response personnel with safety and protective gear, and manual cleanup equipment. In addition, two portable, state-of-the-art command trailers with computer and communication capabilities have been constructed and are located in Nanaimo and Surrey.

Resource Information and Planning Initiatives

The Environmental Emergency Services Branch has undertaken a number of programmes related to environmental, human and logistical resource information and planning. These include shoreline video taping, computer inventories, sensitivity and countermeasure shoreline mapping, development of an electronic oil spill response information system and several volunteer projects.

The Branch has commenced a shoreline video taping programme where the shoreline is taped at low tide from a helicopter flying slightly offshore at low altitude. The tapes provide physical and biological information for shoreline biophysical and sensitivity mapping and a record of the shoreline prior to a spill event and shoreline oiling. They are also useful as a rapid method for oil spill specialists, who may be unfamiliar with the British Columbia coast, to gain knowledge of the shoreline character.

After a region has been video taped, the raw tapes are edited with location and resource maps incorporated. A narration is added to each tape that describes the important physical and biological features of the shoreline. The tapes are catalogued for rapid and easy access, and duplicated for the regional Response Teams. Areas currently video taped and catalogued include the Strait of Georgia and the southwest coast of Vancouver Island from Victoria to Tofino. Some of the tapes used in these areas were flown in the early 1980's by the Ministry of Environment and Environment Canada.

A second initiative related to resource information is the development of computer personnel and equipment inventories. A computer directory of British Columbia Environmental Resource

Oil Spill Specialist has been created to assist oil spill emergency planners and response personnel in the event of an oil spill. The directory lists environmental resource specialists who have past spill experience, selected marine scientists with unique expertise or access to resource information and databases, and native band contacts. Each listing provides data that describes discipline expertise, area of geographic experience in British Columbia, and past spill experience. This directory has formed the model for a national 1991 Directory of Canadian Marine Oilspill Specialists (Harper, J. R., W. Duval, J. Haggarty, J. Dempsey, L. Solsberg, B. Humphry and G. Tidmarsh - these Proceedings). A computer inventory of oil spill equipment located throughout the Province is currently under development.

Shoreline sensitivity and countermeasure mapping has been identified in several studies as required information for establishing protection and cleanup priorities during a spill (e.g. Anderson, 1989; Harper, 1986). To meet this requirement, the Environmental Emergency Services Branch has initiated an Oil Spill Response Atlas Programme. The purpose of the programme is to:

- Map environmental shoreline resources and develop sensitivity maps based on this environmental information.

- Develop and plan oil spill countermeasures for the shoreline prior to a spill.

- Incorporate this information into an atlas for the transfer of detailed environmental information in a simple and rapid manner during a spill, and help establish protection and cleanup priorities.

The Atlas' can also be used for oil spill planning and training, and integrated coastal resource management. The sensitivity ranking model is complex and has been significantly modified from its original model developed in the Environmental Atlas for Beaufort Sea Oil Spill Response (Dickins et al., 1987). The model is based on four themes: Human Use, Biology, Physical Shoreline Character and Special Status Area.

The Branch has completed an "Oil Spill Response Atlas for the Southwest Coast of Vancouver Island" (Dickins et al., 1990). Regional and operational information is presented in the Atlas. There are 19 operational areas in the study. For each operational area, there are two 1:40,000 scale maps: a sensitivity and resource map, and a countermeasures and access map. The operational maps are accompanied by text that summarizes resource information, including seasonal shoreline use, and appropriate countermeasure options for each shore segment.

Native coastal communities and bands were involved and made significant contributions in the identification of sensitive shorelines and coastal resources. The Branch has initiated a second Atlas for the Southern Strait of Georgia and is in the process of collecting the resource data, including native heritage and subsistence gathering sites, required for the sensitivity ranking and mapping (Harper, J. R., Howes, D.E., and Reimer, P. D. - these Proceedings).

In addition to the sensitivity and countermeasure mapping on the southwest coast of Vancouver Island, the Branch has supported a research project with the University of Manitoba related to the identification and assessment of oil debris disposal sites (Moche, E. - these Proceedings). The project reviews past criteria and guidelines for site selection, develops standards and guidelines for the west coast and identifies potential temporary disposal sites between Tofino and Sooke Harbour. The final report and results of this study will be complete by June 1991.

A major initiative related to resource information and data analysis undertaken by the Branch is the development of an electronic Oil Spill Response Information System (OSRIS). A Feasibility Study and A System Design and Technical Requirements Study for OSRIS have been completed. Implementation is expected to commence this year.

OSRIS is being designed as a decision support system that will perform the following functions:

- Pre-oil spill planning including shoreline sensitivity mapping and pre-spill countermeasure strategies;

- Oil spill response functions such as re-evaluation of countermeasure options based on real time data and storage of oil spill data (e.g. degree of shoreline oiling, environmental impacts); and,

- Post-spill monitoring and resource impact assessment and valuation.

Benefits of the system will be improved pre-spill consensus on sensitive shorelines, equipment deployment and cleanup logistics, resource impact assessment and ability to conduct litigation. The system will reduce costs by improved logistics and reduced environmental and economic damage associated with spills.

The Branch has commenced work on two volunteer projects. These are the "Beached Bird Survey Programme" and a Coastal Oil Spill Auxiliary.

The Beached Bird Survey Programme was initiated to monitor seabird mortality and the effects of small, chronic oil spills along the British Columbia coast. Systematic, monthly surveys of beaches along the British Columbia coast are conducted by volunteers or volunteer groups who are trained to identify and collect dead bird species, and to record their cause of death and the beach conditions at the time of survey. This information is forward for entry into a government computer database. Dr. Alan Burger, a biologist with the University of Victoria, has been contracted by the Branch to co-ordinate this program and to train volunteers.

Information obtained from this beached bird survey, as indicated by similar surveys conducted elsewhere around the world, is expected to be an effective and economical method to monitor the timing, distribution and impact of small, chronic spills. Other surveys have demonstrated to be effective in documenting the effects of illegal oil discharges, which in turn, has lead to stricter operational controls and subsequent decline in pollution. Information obtained in these surveys is also expected to improve the capability of the Government in the assessment of environmental impacts that may result from a larger spill event.

Finally, a Coastal Oil Spill Auxiliary System is being developed in cooperation with industry and federal agencies to identify, train and register members of the public who can effectively participate in a response to a major oil spill. The first phase in the development of this system has commenced and includes identifying interested people and organizations, developing a mutual understanding of responsibilities, creating an electronic database of volunteers that details their skills and expertise, and preparing a training and education package.

Summary

The Environmental Emergency Services Branch created in 1990 has undertaken several initiatives related to oil spill response and prevention on the west coast. Despite the accomplishments of the Branch in a short period of time, it recognizes that extensive work remains related to these issues. The Branch will continue its approach to pursue the resolution of these issues in co-operation with industry, various agencies of the federal government and the public. As part of this approach, the Ministry of Environment has established a Citizen Advisory Committee to monitor the progress of programmes and initiatives.

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SUMMARY OF THE IDENTIFICATION AND ASSESSMENT OF POTENTIAL OILED DEBRIS DISPOSAL SITES TO COMPLEMENT BRITISH COLUMBIA'S EMERGENCY CLEAN-UP EFFORTS OF MARINE OIL SPILLS ALONG JUAN DE FUCA STRAIT

by

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ABSTRACT

This research project was undertaken to examine the need for oiled debris disposal sites on the southwest coast of Vancouver Island along Juan de Fuca Strait, and to identify potential disposal sites between Sooke and Tofino based on site specific physical, environmental and social considerations encompassed by site selection criteria. This study involved an extensive literature review, numerous interviews and on-site field work. Limitations, constraints and local concerns along the coast were explored, a suitable size of working area for these sites was examined on the basis of the primary influential factors, and pertinent site selection criteria were developed. The conclusion is that very limited potential oiled debris disposal sites are available along the study area, but nevertheless, the potential occurrence of a major oil spill in the Juan de Fuca Strait dictates their need, and past experience would urge the approval of any designated sites through a public review process.

INTRODUCTION

The primary purpose of this study was to identify and assess potential oiled debris disposal sites, for the treatment/disposal of contaminated organic and inorganic materials arising from oil spill incidents along British Columbia's coast by means of the development of site specific selection criteria. The specific study area along British Columbia's coast for this research project was the southwest coast of Vancouver Island, along the Juan de Fuca Strait, between the communities of Sooke and Tofino (see Figure 1). This area is recognized as a high risk area by the "States/British Columbia Oil Spill Task Force".

An immediate problem concerning marine oil spills within this study area is the current lack of suitable predesignated oiled debris disposal sites for use in conjunction with coastline clean-up measures. Since the main objective in an oil spill clean-up is to react as quickly as possible so as to minimize environmental damage, predesignated sites for the treatment/disposal of large volumes of organic and inorganic contaminated materials are required. The need for such disposal sites has been emphasized by the Canadian Coast Guard (Western Region) and Mr. David Anderson in 1989, and the States/B.C. Task Force and Canada's Public Review Panel in 1990. The availability of such sites would improve response preparedness, and potentially reduce environmental damage and law-suit costs for damage compensation which can threaten the sustainability of off-shore transportation of oil or of development of off-shore oil resources.

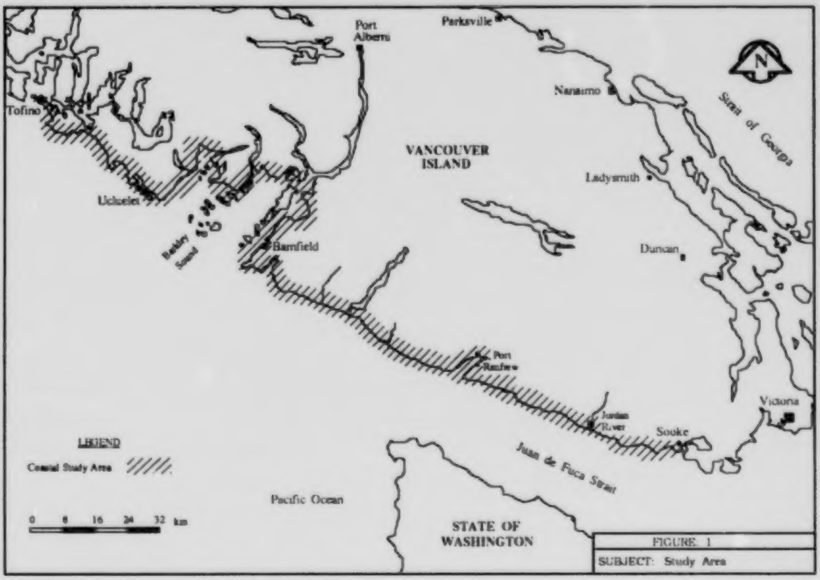
Port Alberni
Parksville
Nanaimo
Strait of Georgia
Tofino
VANCOUVER ISLAND
Ladysmith
Ucluelet
Barkley Sound
Bamfield
Duncan
Port Renfrew
Victoria
Jordan River
Sooke
LEGEND
Coastal Study Area
Juan de Fuca Strait
Pacific Ocean
0 8 16 24 32 km
STATE OF WASHINGTON

FIGURE 1
SUBJECT: Study Area

LITERATURE REVIEW ON THE STUDY AREA

Oil tankers first began moving along British Columbia's coast in the late 1960's with the opening of the Alaska oil fields. Currently some 220 tankers, some of them carrying as much as 200-million litres of crude sail by Vancouver Island every month, with an ever increasing number steering into the narrow Strait of Juan de Fuca to unload at the Cherry Point facility in Washington's Puget Sound (Western Report, 01/23/89). Oil spills have already occurred in the region, and have already affected B.C.'s environmentally sensitive coastline. This problem is a new phenomena for British Columbia because, until recently, no major oil spills had occurred in this region.

In examining the study area for potential oiled debris disposal sites, the following influential factors were studied:

Coastal Geomorphology

Most of the southwest coastline of Vancouver Island comprises bedrock consisting mainly of mid-Tertiary augite gabbros and basalts with lesser amounts of late-Tertiary sandstone, shale and conglomerate. Within the study area, the shoreline is featured with wide rocky intertidal wave-cut platforms, pocket sandy beaches, rocky headlands, and abundant inlets and fjords. The remaining shoreline consists of unconsolidated Quaternary sediments of till or glacial-fluvial deposits and are the source for much of the shoreline sediment cover. Overall, the beach cover progresses from pebble-cobble material west of Sooke to fine sand and gently sloped continuous beaches at Long Beach near Tofino. The backshore is generally tree covered, with large beached driftwood marking the high tide limit. Farther inland, the terrain ranges from gently to very steeply sloped land overlain mostly with shallow glacial till supporting a dense forest cover.

Coastal Meteorology

Climatic conditions along the study area are of significance to oil spill clean-up activities and associated safety concerns, as well as to the establishment, operation and maintenance of oiled debris disposal sites.

Temperatures affect the viscosity and pour point of oil, and hence the degree of success in recovery and clean-up. Although the monthly average minimum temperatures are above 0°C, extreme minimum temperatures of -15.0°C, -11.7°C and -13.9°C have been recorded at Tofino, Ucluelet and Sooke, respectively, for December-January. Extreme maximums for these stations in June-July have been recorded as 32.8°C, 28.9°C and 29.4°C, respectively (Atmospheric Environment Service).

Precipitation increases the water content and weight of the collected oiled debris, induces run-off losses, prevents on-site burning, and presents storage problems for the adequate containment of the collected oiled debris. Available precipitation data for the study area shows the following:

Location	Avg. Total Precip./yr	% > than at Sooke
Sooke	1287.4 mm	-
Ucluelet	3077.3 mm	139 %
Tofino	3288.3 mm	155 %

The maximum monthly rainfall occurs at Tofino, during December, with the registered monthly average being 480 mm of total precipitation. On the average, rainfall occurs on 195 days out of the year at Tofino and Ucluelet, and 165 days out of the year near Sooke, with snowfall amounting to an insignificant contribution (Atmospheric Environment Service).

Winds influence surface currents and wave action, and will thus affect the oil spill distribution and marine accessibility to shorelines. Winds can also influence the suitable location of oiled debris disposal sites where incineration may be practiced. In Juan de Fuca Strait the prevailing wind direction during the winter is from the east and southeast. Between October and March winds at more than 60 km per hour occur for 10 to 15 days each month (Owens, 1977). Maximum hourly wind speeds of 100 km/hr with maximum gust speeds of 130 km/hr have been recorded at Tofino in November and December, respectively, between 1960 and 1980 (Atmospheric Environment Service). In the summer, the prevailing winds are from the west and northwest, and are more moderate, with speeds reaching 60 km per hour on only 1 or 2 days per month (Owens, 1977).

Oceanography

Tides in Juan de Fuca Strait are typically mixed semi-diurnal with two complete oscillations daily. Fluctuations between high water and low water tidal elevations range from 4.78 metres at Tofino, to 4.05 metres at Ucluelet, to 4.11 metres at Bamfield, to 3.6 metres at Port Renfrew, decreasing in magnitude easterly towards Sooke (Fisheries and Oceans, 1989). The semi-diurnal tides and the tidal range characteristic to the study area, present frustrating clean-up problems along shallow-sloped beaches such as Long Beach, and pose dangers for marine access to beaches along coastlines lined with rocky intertidal wave-cut platforms. This has ramifications for the collection of oiled debris.

The coastal area most likely to be impacted by a marine oil spill will be primarily determined by the mean direction of flow of surface currents within Juan de Fuca Strait. The complexity of predicting the direction of surface currents has prompted drift card research to verify and adjust computer modelling predictions. Such modelling has predicted an oil spill at the entrance to Juan de Fuca Strait to migrate westward toward the open seas but also to move north in the winter towards Vancouver Island, such that the most probable impact zone during the winter would extend from Sooke to Tofino within 7 days (Wolferstan, 1980).

The coastline west of the entrance to Juan de Fuca Strait is exposed to high level swell wave energy which has a significant bearing on the longevity of the oil on the affected coast. At the western entrance, wave heights can exceed 6 metres 10% of the time in the winter, and decrease to moderate heights of 1.5 to 3 metres within the shelter of the Strait (Thomson, 1981).

Oil Transport Traffic Within the Study Area

The emerging importance of the requirement for oiled debris disposal sites to complement emergency oil spill response plans is apparent from the increasing traffic of oil transport along the study area. The following documents the amount of traffic in Juan de Fuca Strait in 1988 (States/B.C. Task Force, 1990):

	Volume of oil	Type	# Tankers	#Barges
(Imported)	25.4×10^6 m^3	crude	330	35
(Imported)	1.0×10^6 m^3	refined	-	-
(Exported)	0.91×10^6 m^3	crude	14	-

Future predictions offered by the States/British Columbia Oil Spill Task Force indicate that crude oil imports through Juan de Fuca Strait are forecast to increase by about 5% per year. Exports from Alberta are expected to increase to 2.2 million m^3 (48 tanker shipments) per year, possibly increasing to 139 tankers shipments per year by the late 1990's.

Risk analyses carried out on the status quo situation by the Task Force indicate the following oil spill probabilities for the study area:

Spill Size		Probability of Occurrence
159 m^3	(1,000 barrels)	once in 2.5 years
1,583 m^3	(10,000 barrels)	once in 20 years
15,876 m^3	(100,000 barrels)	once in 210 years

A computer model of a spill scenario carried out for the Task Force, and based on an oil spill of 30,160 m^3 (190,000 barrels) of crude oil in U.S. waters within Juan de Fuca Strait, determined that within 61 hours of the spill, 80 km of canadian shoreline would be affected by 87,220 m^3 of emulsified oil.

METHODOLOGY

Aside from the literature review, extensive field work was carried in the study area. The entire study area was explored by vehicle and foot, where accessible, and viewed from the air by helicopter, with much of the area documented with photographs and video recordings. Also, available aerial photos, topographical maps and soils and terrain maps were compiled and scrutinized. In addition, numerous on-site interviews were held with local oil spill clean-up volunteers, government and municipal staff, and elected officials.

Difficulties encountered in course of the field work consisted of limited or restricted road access to areas of potential interest, outdated aerial photographs and logging road maps, and the absence of up-to-date land tenure maps to distinguish between private, leased and vacant Crown lands.

RESULTS AND CONCLUSIONS

The results and conclusions arrived at from the literature review, field data and personal interviews can be summarized as follows:

1) The literature review and field interviews supported the need for oiled debris disposal sites. However, the strong consensus of the public was that, if such sites were to be established, these sites should only serve a temporary purpose. The expectation was that the oiled debris sites should not be intended as a permanent disposal option. As well, the view was that fewer larger sites, rather than numerous smaller sites, would be preferable from the perspective of proper maintenance.

2) In addressing the problem of identifying potential oiled debris disposal sites, a balance must be found between the number of sites and the size of those sites based on the amount of oiled debris which might have to be handled as a result of a marine oil spill. In using the Exxon Valdez oil spill as a worst case scenario, and incorporating variable factors which can influence the impact of the spill upon the coastline within the study area, as well as assuming that only 31% of this coastline would be accessible for beach clean-up, an estimated amount of 134,000 m^3 of oiled debris might be generated from a 40,800 m^3 oil spill of Alaskan crude oil. If about six sites were established, then a minimum of two hectares of working area at each site would be required. However, this evaluation has to be treated only as an academic estimate because literature correctly cautions that there is no close correlation between the size of an oil spill and its impact (States/B.C. Task Force, 1990).

3) The design of an oiled debris disposal site is highly contingent upon the manner in which the facility is expected to be used and operated. In this regard, the most limiting physical factor which will influence the design of these sites was determined to be the high levels of precipitation experienced within the study area. Presuming that an oil spill were to occur in December and impact Long Beach, the average amount of precipitation in this area, over that month, would equate to each hectare of land area receiving 4,800 m^3 of precipitation. If the oiled debris disposal site is operated in such a manner that oiled debris can come in contact with the precipitation, then all of this contaminated water would have to be collected and treated during the course of the site's active use. This may prove impractical such that it may be preferable to store the oiled debris on site in water-proof containers for future treatment.

4) Site selection criteria were developed based on local physical, environmental and social considerations. Elements which were stressed were: accessibility, surficial gradient, surficial and sub-surface soil types and thickness, proximity to water supply sources, proximity to natural waterways, available working area, immediate and surrounding land use, land tenure, and prevailing wind directions.

5) Based on the literature review, field surveys, data extracted off available maps, and the developed site selection criteria, the study area revealed a very limited availability of potential oiled debris disposal sites, particularly in consideration that the quest focused on areas already disturbed by clear-cut logging and yet not too removed from the coastline. Nevertheless, a number of potential

oiled debris disposal sites were identified, but these sites may require more in depth site investigations to confirm their suitability.

6) Based on problems which were encountered in the clean-up of the Nestucca oil spill, as well as interviews of native representatives and the general public, any potential sites intended to be designated for use as oiled debris disposal sites should be subjected to a public participation process.

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THE VALUE OF LARGE SCALE EXERCISES IN AN OIL SPILL RESPONSE TRAINING PROGRAM THE EXPERIENCES OF THE IMPERIAL OIL NATIONAL EMERGENCY TEAM

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ABSTRACT

Imperial Oil has held annual large scale exercises each of the last two years, and has gained considerable experience in how these simulations should be conducted. The structure of the exercise and the selection of participants will be described. The balance between the exercise length and the learning experience will be discussed, as will the issue of timing the arrival of National Emergency Team (NET) members from distant locations in Canada.

A. INTRODUCTION

"The most valuable exercise I have been involved with" quoted from a participant in Imperial's major simulation.

The readiness and ability of the Canadian petroleum industry to respond to spills has been the subject of a number of enquiries during the past two years. (TFOSP, Brander-Smith and David Andersen). Each, in its own way, has concluded that the ability to respond is a function of the availability of equipment, the ability of staff to operate this equipment and the establishment of a structure to manage the spill. These reports have identified training as an essential factor in the development of the skills needed to operate equipment and to manage the spill.

One of the major problems in oil spill response training is the lack of practice for the team members. Oil spills are rare, and many response professionals can work a whole career without having the experience of responding to anything beyond minor spills. The same people must however be trained and competent to respond to a spill at a moments notice, and the quality of their decisions and management skills will be judged critically by company management, the government agencies, the press and ultimately the public.

In the past most of the training has been directed at equipment handling, with an emphasis on the deployment of booms and skimmers. This trains industry staff in the mechanics of oil spill response but does not place any emphasis on management structure. In order to successfully complete a boom deployment exercise, several weeks of planning are needed. This planning does not take place in a time-pressured environment that would occur during an actual incident. At the other end of the training spectrum is the paper simulation, which is designed to test the structure of the management of the spill. These exercises involve the development of a scenario to which the team responds using incident reports to drive the simulation. It is this type of exercise that tests the ability of the response organization to manage a spill.

Once the initial training on skills development and basic strategy has been completed, there is the problem of keeping people aware of the basics and expanding their experiences to the issues involved in a major spill situation and to maintain a high state of awareness and training. One method that has been used is the development of a computer-based training program called SPILL COMMANDER (Peabody Goodman). The war-game program allows a student to respond to a computer driven scenario. Decisions involving the allocation of resources, the prioritization of response activities and the development of a response structure are exercised using this training tool. The computer-based simulation does not however test the ability of a spill manager to delegate authority, to interact with other response staff, to allocate his time or to develop a dialogue with a head-office crisis management function. These later skills can be best performed by undertaking a major simulation.

B. WHAT IS A MAJOR SIMULATION ?

A major simulation is similar to a standard communications exercise and involves the development of a scenario to which the emergency team responds. The characteristics which separate a communications exercise from a major simulation are one of scale. A major exercise would incorporate a number of features such as:

1. Length of exercise

While a typical communication exercise would last for a standard work day, a major simulation should last at least 24 hours and preferably 36 to 48 hours. This tests the ability of response staff to maintain a continuing dedicated response effort, and to hand over the activity.

2. Geographic extent of response function

A major simulation should involve at least two command centres, one at head office and one at a field location. Additional regional command centres or a distributed field response could be added to increase the complexity of the simulation. The geographic distribution of the response effort tests the communication facilities, the ability of the response structure to devolve authority and puts an emphasis on the inter-personal communication capabilities of all concerned.

3. Support personnel

A major simulation involves a number of support staff whose role is to provide the logistics for the response effort. This includes supplies, radio communications, procurement and transportation coordination. This staff must provide the actual logistics of the simulation as well as participate in the simulation. It can be a challenge to feed a hundred when you did not know anyone was coming.

4. Media

The coverage of the spill incident by the media has been identified as an integral component of a response function. A major simulation should involve the corporate media staff at all locations to provide appropriate and positive media coverage. The use of agressive simulators with real press experience is essential to provide a suitable press pressure. This tests the ability of the corporate media to respond to a crisis situation and provides response staff with a sense of the demands of the media during an emergency situation.

5. Corporate Support

The successful response to a spill requires the support of a number of staff from corporate departments such as legal, claims and insurance, human resources and finance. Many of these people have little awareness of their roles in the response to an incident. A major simulation must include this group.

C. DEVELOPMENT OF MAJOR SIMULATION

The development of a major simulation requires a large amount of effort and planning. At least six months should be allowed for the preparation of a major simulation. The following points serve a road map for the development of a realistic exercise.

1. Establish Ownership, Set Objectives

Simulations may be designed to test a great many different aspects of a response plan. It is essential that a senior manager take ownership of the simulation and specify the key areas that must be developed through the exercise. These can be broad objectives such as:

* Integration of regional teams with national resources
* Communications flow from response locations to senior corporate management.

In addition, it is possible to include some specific objectives such as:

* Test a specific decision making network
* Test a specific piece of hardware

Experience indicates that you cannot test all possible elements in a simulation. Three to five objectives are all that can be reasonably balanced.

Besides establishing the objectives for the exercise, the senior manager, because of his authority, can ensure that the simulation team is adequately staffed and funded to allow all of the objectives to be accomplished. He will be responsible for key decisions such as the level of involvement of external authorities, the involvement of media, and the extent of field deployment of response devices.

The timing of the simulation must be set so that all key management personnel can set the time aside within their calendars.

2. Select simulation coordinator and team.

Designing effective major simulations requires a skilled project team who are knowledgeable in the key aspects that will be exercised. Examples of the type of expertise include:

* knowledge in the behavior of spilled oil and spill fate projections
* legal expertise
* response techniques
* familiarity with the local contingency plan
* knowledge local government emergency procedures
* marine casualty
* public affairs
* communications hardware

Basically the project team needs to be as skilled as the response team to ensure that the exercise is thorough and that all responders are kept fully involved in the simulation. The resources that are used to plan the simulation must not significantly reduce the number of people available to respond to the simulated crisis.

3.Finalize the ground rules

Detailed ground rules for a major simulation are essential since they form the basis under which the drill is conducted. Pre planning is needed at this stage to define issues such as:

* the degree of interaction between responders and external authorities, suppliers, etc. (or the need for simulators to role play key authorities);
* the length of the simulation;
* the timing for participation of responders from offsite;
* the extent of field activities; (few in January)
* the rules for observers; (observe only)
* the rules for simulators; etc.

These ground rules should be developed early and thoroughly reviewed with the simulation owner (senior manager) to ensure that they are consistent with the simulation objectives.

4.Scenario outline

The simulation by definition is the response to an incident. This step develops the general details of the incident that could develop over the course of the one or two days. This general outline forms the basis around which all of the "challenges" will be framed. "Challenges" are the requests that the simulators give the players that direct them to provide certain information. It is these requests that stimulate the responders go through all of the tasks required to fulfill their role. These challenges require an interaction among all responders and are the basis for exercising effective interpersonal communication skills.

5.Scenario Execution Details

Thus far, the simulation is only scripted. Receiving a copy is not very realistic and it does not happen in real life. The simulation team has the challenge of breaking the script into realistic pieces of information or challenges. Each is then identified with respect to who on the simulation team will transmit the information, when it will be transmitted, and to who at where it will be given. The end product is then the simulation package. If this is done well, participants will come to believe that the simulation conditions are reality. Imagine a simulation with warm sunny weather conditions where participants wander out in shirt sleeves to find the weather is cold clammy rain.

The simulation package is the framework for simulation execution. During execution of the simulation, however, the responders may take actions not anticipated or may miss key steps. It is necessary to have a dynamic process that allows the simulators to ensure that the responders adequately deal with the key issues.

6.Don't forget the logistical needs for the simulation

Executing a simulation requires a tremendous attention to detail. Care should be taken to ensure that the basic requirements of accommodation, food, transportation, communications are well looked after. In addition there is a myriad of minor details such as telephone numbers for the simulators who could be playing a variety of roles that the response team may need to contact, office space for the simulation team, stationary, pagers, fax machines, copiers, cameras, video equipment, etc.

7.Plan to capture the learnings

It is critical to capture the learnings from a major simulation so that follow-up activities can be planned and executed. This could involve the creation of a simulation critique form, providing guidelines on the debriefing and the use of independent observers. Observers should form a key component of the plans to identify learnings given that the simulators and responders are typically fully committed to their roles.

8.Simulation Execution

Simulation execution, depending on the ground rules, should be as realistic as possible. Full use should be made of telephones, faxes, and radios to contact the responders with details of the incident or with requests for help or with information or with offers for services or with the outrage from the concerned public.

Do not underestimate the number of simulators required to execute a major simulation or overestimate the capability of one simulator. During the execution of a simulation, because of responders being unavailable for a period of time, placing one piece of information may require several attempts at contact. The execution plan should also consider the need to have alternate simulators during the course of an exercise that goes beyond 16 hours. The execution should also avoid the need to have a simulator to role play more than one major role.

If the simulation involves exerting pressures that could occur in managing media requests for information and interviews, then the execution team must include staff capable of responding as the real media could. They should as a minimum be capable of exerting pressure during scrums and developing news articles based on their understanding of the events. The use of experienced media consultants is recommended.

Coaches can also be excellent addition to any simulation. A coach by our definition is a knowledgeable individual who has the task of monitoring the response and directing the responders at how they can be more effective. They are not allowed to do any of the tasks for the responders.

9. Don't forget to budget both time and money for the simulation

Our experience indicates that development of a major simulation from the time the project team is assembled requires about one hundred and fifty man days. The extent of effort also increases if there is significant involvement of external authorities, consultants or if it is to involve complicated logistical preparations.

Total cost estimates for simulations should include all hard costs such as facility rentals, consultants, equipment rentals as well as the time and travel costs for both the simulators and responders. The total number of people involved is simply a function of the simulation. Our last involved over 150 response staff including representatives from the following:

- Canadian Coast Guard
- Environment Canada
- Nova Scotia Department of the Environment
- ESSO's regional response team
- ESSO's national emergency team
- ESSO's marine casualty team
- ESSO's crisis communications team
- ESSO's crisis management team

D. VALUE OF MAJOR SIMULATIONS

The success of a major simulation is strongly dependent on the quality of the simulation design. Each simulation identifies different aspects of a response situation and hence provides new learning experiences.

One of the main purposes of a major simulation is to exercise and enhance the skills of the local, regional and national response teams. For the first simulation in an area, this involves a good deal of personal interaction between the various teams. The individuals with technical responsibilities can exchange information and techniques and provide training for each other. Members of the national team learn the geography and develop contacts in the region.

The running of a large scale exercise tests the quality and functionality of the local contingency plan. Experience has shown that such a test generally results in revisions to the contingency plan based on the issues encountered during the simulation. There are a number of implicit assumptions made in contingency plans regarding the capabilities and response actions of government agencies. Since representatives from these groups are included in the simulation, the validity of the contingency plan assumptions can be tested and verified.

As with any other group activity, simulations help develop a team spirit among all the response groups. The development of personal relationships with other team members is very important and gives confidence to all team members. This is very important during an actual incident. The various team members already know each other and can therefore quickly develop a dynamic team to respond to the situation.

These large long term simulations test both the design of the response effort and the interpersonal skills of the team members. The total immersion in the exercise simulates well an actual spill situation and the intensity of interaction between people required by all responders. Personality conflicts, the ability to identify and handle stress as well as technical skills are thoroughly tested during a long term situation. People do get emotional, tempers flair and conflicts develop. The handling of these is one of the challenges of such a scenario.

E. CONCLUSIONS

There are a number of ways to train oil spill response personnel in handling the spill situation. One is to have a number of spills a year so that experience is gained in spill response under actual field conditions. This is undesirable from both an environmental and regulatory viewpoint, so the alternative is to use simulations. Experience has shown that while short-term simulations are useful for initial training, a longer time and more complex scenario is needed to identify problems with a spill response plan and to develop responders experienced in working under a stress situation.

While such simulations are costly both in terms of expense and manpower, they are the only way to truly "exercise" your response capability.

F. ACKNOWLEDGEMENTS

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DEVELOPMENT OF A DIRECTORY OF CANADIAN MARINE OILSPILL RESPONSE SPECIALISTS

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ABSTRACT

This paper provides an overview of the development of the "1991 DIRECTORY OF CANADIAN MARINE OILSPILL SPECIALISTS", developed during 1990 and 1991 through ESRF funding.

Although oil spill contingency plans may cover a wide range of oilspill scenarios, the complexity of regulatory, environmental and spill characteristics makes each spill unique. To assist the On-scene Coordinator and advisors with decision-making during spill events, resource specialists are often required on short notice to provide information that cannot be incorporated in advance into response plans. Resource specialists listed in this directory form a vital component of this information base.

Two critical evaluations were conducted during development of the directory:

(1) Screening Responses - inclusion in the directory was limited to individuals with previous spill experience or to individuals with a unique expertise in a critical resource area.

(2) Cross-referencing - a detailed keyword index was developed to assist in referencing individual expertise and a spill index to reference individual spill experience.

The directory includes approximately 250 individuals. Each record includes a name, contact information (address and phone no.), resource specialties, and spill experience. The directory is printed in hard-copy and is also available in a dBase III Plus file format.

Recommendations resulting from the development of the directory include: (1) the directory be updated annually, (2) "regional" versions of the directory be developed to include additional local resource contacts, and (3) consideration be given to development of an international directory of response specialists.

INTRODUCTION

Although oil spill contingency plans may cover a wide variety of oilspill scenarios, the complexity of environmental, regulatory and spill situations makes each spill unique. To assist the On-Scene Co-ordinator in decision-making, resource specialists are often required at short notice to provide information that cannot be incorporated in advance into response atlases. As Harper (1987) noted in his review of decision-making during spill events, environmental advisors are a critical information source at the time of the spill, and generally the more information that is available early in the emergency, the more informed the decision-making. The resource specialists listed in the National Directory form a key component of this information base.

The primary goal of the project was to list and catalog resource specialists that could be of assistance to response personnel during a spill, particularly during early stages. Specific objectives of the project were:

1. Provide sufficient address details to permit easy contact,

2. Provide a **keyword index** summarizing an individual's primary areas of expertise related to spill response.

3. Provide a **geographic index** indicating regions where an individual has had first-hand field experience.

4. Provide a **spill experience index** that summarizes an individual's experience at specific spill events.

The Directory was not intended to (a) supersede contingency plan call-out lists, (b) list corporate experience or (c) list oilspill planning/response products.

TECHNICAL APPROACH

Overview

The development of the Directory involved two competing goals. First, it was desirable to incorporate as wide a range of expertise as possible in terms of response personnel. On the other hand, it was also considered important to identify individuals who had been involved with previous spill events; this previous experience would be particularly important during the early part of the spill when critical decisions are being made.

As a result of these competing goals, the decision was made to advertise in oilspill-related publications so as to concentrate efforts on individuals that would most likely have had previous spill experience. Notification of the Directory development was provided through various industry publications including the Oilspill Technology Newsletter, Oil Spill Intelligence Report and Arctic Petroleum Review. In as much as possible, industry cooperatives with marine spill experience also were contacted. In addition, a direct mailing to over 450 individuals was made early in the project. This included individuals listed in the British Columbia Oilspill Directory (Harper and Howes, 1990), government contact lists and personal contacts of project team members.

At this initial step, the decision also was made to limit the Directory to individual's with field experience in Canada. It was recognized that many individuals without Canadian experience could meaningfully contribute to response decision-making; however, for the development of this first directory, this step was considered important in limiting the scope of the responses. This concern may be addressed by future regional or international directories.

Directory Development

The development of the Directory involved five major steps:

Questionnaire and Keyword Listing Development - a questionnaire was developed to illicit relevant address and background information for individuals. A key element of this questionnaire was that it should be simple and rapidly completed (2-3 minutes). At the same time, a keyword glossary was compiled to provide consistent terminology for summarizing individuals' experience.

Notification and Questionnaire Circulation - direct mailing was initiated at the same time that the directory was announced in the industry publications.

Screening - as questionnaires were returned, each was screened against a set of "inclusion" criteria (see below). Questionnaires were categorized for: inclusion, further info required, additional review, or "exclusion".

Review - questionnaires indicating a potentially unique expertise or those slated for "exclusion" were reviewed by three project team members: the Project Manager, a discipline specialist and a regional specialist.

Compilation - a customized dBase III Plus database structure was developed for cataloging the directory. This database was used for generating mailing labels, tracking questionnaires, providing consistency within the database, indices development, and final printing.

Screening

As previously indicated, the conflicting goals of (a) having as wide a range of specialists as possible and (b) limiting the directory to specialists with previous spill experience provided a challenge to the directory development. The former goal increased the number of listings, while the later goal limited the number of listings. As a result, a set of "inclusion" criteria was developed to provide a consistent approach to the screening process.

The inclusion criteria are summarized in Figure 1. The criteria are as follows:

Criterion 1 -	does the individual have Canadian field experience? If yes, apply Criterion 2. If not, exclude from the directory.
Criterion 2 -	does the individual have previous spill experience? If yes, apply Criterion 3. If not, refer to review process, Criteria 4.
Criterion 3 -	was the individual's experience in a decision-making, managerial or supervisory capacity? If yes, include within the directory. If not, exclude from the directory.
Criterion 4 - (Team Review)	does the individual have a unique area of expertise which has been of demonstrated use in previous spills or is likely to be of use in future spills? If yes, include within the directory. If no, exclude from the directory. This Criterion was evaluated by a review team composed of the project manager, a discipline specialist, and a regional specialist; in all cases the review was by consensus.

RESULTS

Responses

At the time of preparation of this paper, the following figures summarize the response to the mailings and Directory announcements:

Questionnaires Mailed:	666
Questionnaires Returned:	349
Individuals Included:	232

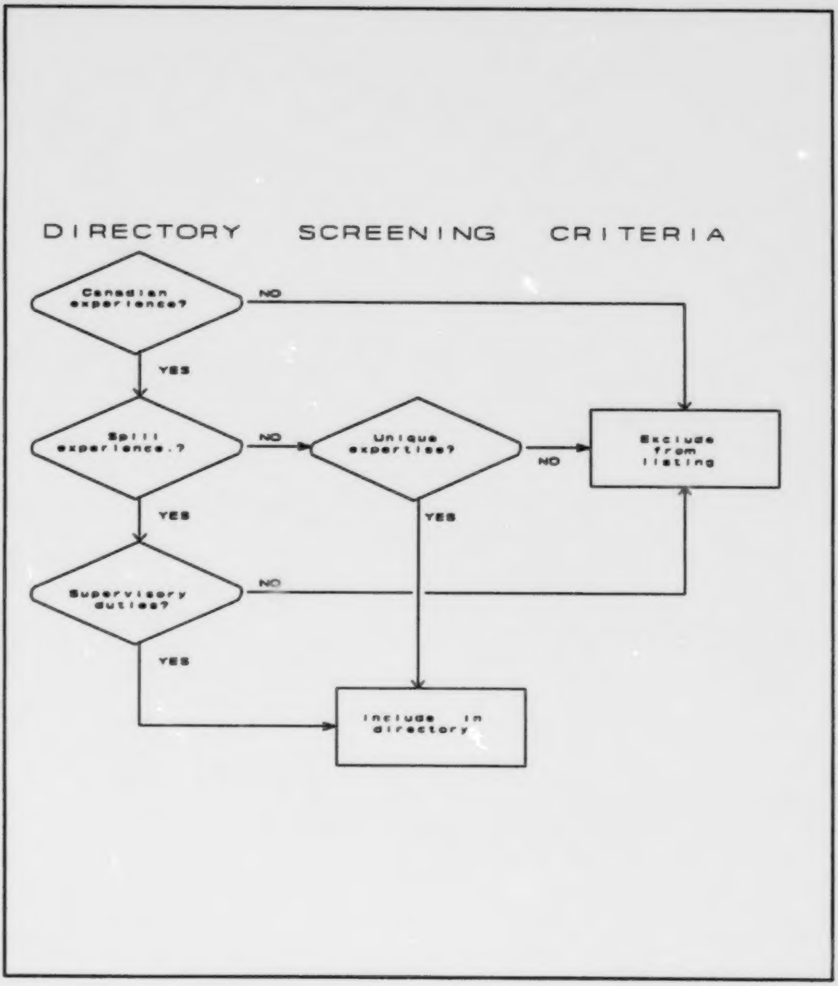
DIRECTORY SCREENING CRITERIA
Canadian experience?
NO
YES
Spill experience.?
NO
Unique expertise?
NO
Exclude from listing
YES
YES
Supervisory duties?
NO
YES
Include in directory

Figure 1. Procedures used in the response screening.

Demographics

The geographic representation by region is:

Region	Number of Listings	
Pacific	130	
		130
Beaufort Sea	70	
Eastern Arctic	48	
		118
Newfoundland and Labrador	31	
Maritimes	62	
		93
Great Lakes and St. Lawrence River	70	

Note that the number of listings for each region do not sum to the total number of listings because many individuals are cross-referenced in several regions.

DISCUSSION OF RESULTS

We initially expected a larger number of listings, based on the experience of the British Columbia Oilspill Directory, which included 117 individuals with either previous spill experience or unique expertise but did not include countermeasure specialists. The lower than expected response may reflect the limited audience of the industry publications in which the Directory was announced. Some of the areas that are peripheral to spill response, such as emergency communication systems or spill litigation for example, may not have been reached by the announcements or direct mailings. **It is recommended that subsequent announcements and mailings address this concern.**

Annual updating is recommended to keep the Directory contents current and to expand the scope of the Directory to include peripheral spill response disciplines.

The summary of listings by region suggests a bias towards the Pacific region in terms of number of listings. The relatively higher proportion of the listings for the Pacific Region is probably a result of (a) the use of the BC Oilspill Directory as a source for the initial mailing and (b) the large number of individuals who have had direct experience with the Nestucca and EXXON Valdez spills (98 of the 232 individual listings had experience on one or both of these spills).

In that the compilation was funded by the Environmental Studies Research Fund (ESRF) in support of offshore exploration drilling concerns, the Directory focused on the frontier drilling regions of Canada, i.e. the Pacific Coast, the Arctic and the Atlantic coast. However, it was recognized that numerous individuals with response experience were located within the Great Lakes region, and these individuals were included within the directory.

The directory was restricted to individuals with Canadian field experience which was regional in nature. The Directory is not comprehensive, however, in that there may be individuals without Canadian experience that could contribute significantly to a specific spill response. Similarly, there are numerous individuals that have extensive local knowledge about a small geographic area that would be important resource personnel during a spill response. For example, we included native band leaders within the BC Oilspill directory as individuals who would have a unique local knowledge of subsistence resource use and logistics.

While the development of the 1991 Directory of Canadian Marine Oilspill Specialists represents a significant improvement in cataloguing expertise, **it is recommended that (a) an "International Oilspill Response Directory" be developed to provide a world-wide catalog of spill response expertise and (b) local or regional directories be developed to incorporate local expertise (e.g., fisherman co-ops, community response organizations, native band leaders, etc.).**

ACKNOWLEDGEMENTS

Funding for this project was provided by the Environmental Studies Research Fund (ESRF) through a contract to Harper Environmental Services. We appreciate the advice provided by Mr. Jim Anderson of ESRF, Mr. Rick Hoos of Polar Gas in Calgary, and Mr. Jim Swiss of the Canadian Petroleum Association. dBase III Plus is a registered trademark of the Ashton-Tate Company.

REFERENCES

Harper, J.R., 1986. Practical insights into decision-making for shoreline clean-up of oil spills. Environmental Studies Revolving Fund Report No. 033, 44 p.

Harper, J.R. and D.E. Howes, 1990. Directory of oilspill and environmental resource specialists for British Columbia. Technical Report of the Environmental Emergency Branch, Ministry of Environment, Victoria, BC, 67p.

USING COMPUTER AND COMMUNICATIONS TECHNOLOGY FOR EFFECTIVE EMERGENCY MANAGEMENT

by

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Vancouver, B.C. V6J 4N8

I. The Need For Effective Emergency Management

Recent events in the Persian Gulf, Southern U.S., Hagersville, San Francisco, Prince William Sound, and Saint-Basille Le Grand, among the host of less spectacular events which occur around the world on a daily basis, underline the need for effective emergency management on the part of both government and industry.

There are a wide variety of statutes and regulations in North America that authorize governments at all levels to plan for and respond to emergencies that may fall within their respective jurisdictions. And, as if this legal area wasn't complex enough, there is an over-abundance of legislation here and abroad that establishes requirements for industrial contingency plans.

Existing hazards, both man-made and natural, and legislation provide plenty of incentive for effective emergency management. The high costs of clean-up, liability insurance premiums, and public pressure furnish additional motivation for organizations to take steps to reduce risks to people, property, and the environment.

II. Reducing the Risk

Given our exposure to numerous hazards, including arctic and marine oil spills, there are five expedient means for reducing risks:

1. The first is *prevention*. Prevention includes prohibiting or limiting certain activities, improving physical infrastructure, and enforcing regulations.

2. The second is *public relations or education*. One of the contributing factors to the earthquake survival rate in San Francisco is the high level of public awareness. People in San Francisco know what to do in the event of an earthquake.

3. The third is *planning*. It was Louis Pasteur who said, "Chance favours those who are prepared".

Planning enables emergency managers to make order out of chaos, and to carry out there jobs effectively.

4. Four is *training*. In an increasingly complex world, training helps emergency responders "keep up to speed".

5. The fifth is *emergency response*. Risk is equal to the probability of an event occurring times the consequence. Effective response can significantly reduce the consequences of an emergency.

III. *Soft*Risk, An Integrated Emergency Management Solution

Impact Research Group Ltd. has developed a computerized emergency management system called ***Soft*Risk** for improving productivity and results in planning, training, and emergency response. The purpose of ***Soft*Risk** is to help minimize risks to public health and safety, property, and the environment. The ***Soft*Risk** product integrates a user-friendly and versatile software program with state-of-the-art colour touchscreen technology and communications devices.

***Soft*Risk** can provide substantial support to the emergency planning process. Data entry and management are simplified through the use of advanced-scanning and communications technologies. Scanning enables the user to computerize on a daily basis data, site drawings and maps in any format for quick access and communication. All designated sites are automatically recorded in a versatile, easy-to-use site database. Furthermore, emergency contact lists, resource lists, plans, AutoCAD drawings and GIS maps can be easily scanned, converted, or entered into ***Soft*Risk** using a keyboard.

***Soft*Risk** can be used on an ongoing basis to test and enhance the knowledge and ability of emergency response personnel in a wide range of realistic circumstances. For example, fictitious scenarios can be created to examine and increase knowledge of procedures for response to specific emergencies and site-specific precautions. Decision makers can exercise their ability to make critical decisions given complex emergency conditions and prescribed resources. Training exercises can be logged for evaluation and debriefing purposes.

As an aid to decision making, ***Soft*Risk** reduces critical response time while improving response efforts by quickly providing up-to-date, accurate, and comprehensive response information.

SoftRisk's unique integration of computer components and communications devices enables the two-way transmission of text, graphics, and map-related information within a network and to the field. All information contained in ***SoftRisk*** can be faxed.

SoftRisk is also well suited for field application when installed in a command vehicle. The availability of ***SoftRisk*** to an on-scene commander means direct access to all of the above.

Because of ***SoftRisk's*** resource management features and communications capabilities it may be used in conjunction with computer-aided dispatch systems as a complementary technology.

SoftRisk generates unique and meaningful information for virtually every potential emergency situation by accomplishing ten principle functions:

1. Provides prioritized information on persons, agencies and service organizations to contact for help or for reporting purposes.

2. Generates comprehensive procedures for response to specific emergencies.

3. Presents interactive, colour-coded maps enabling numerous functions such as the ability to instantaneously zoom and scroll, obtain site and route information, draw emergency areas and routes, find streets and coordinates, and deploy resources.

4. Provides quick access to site plans that can contain unlimited text and graphics information.

5. Supports the management of key resources by enabling the deployment of resources to be graphically depicted on interactive maps, and the automatic recording of up-to-date resource allocations in a database and log.

6. Enables logging of emergency response activities while automatically date/time stamping all entries as well as incoming and outgoing fax transmissions and file transfers.

7. Enables quick access to plans for communications, organization, evacuation, mutual aid, standard operations, and more.

8. Presents supporting database information on causes, potential hazards, and impacts of emergencies.

9. Presents lists of organizations that can provide human and material resources.

10. Facilitates two-way text, graphics, and map communications between decision makers, departments, and vehicles in the field. All information in ***Soft*Risk** can be networked.

The versatile ***Soft*Risk** technology is adaptable to a wide range of government, industry and commercial applications in helping to save lives, property, and the environment. This friendly software can be easily configured and customized by users to suit their own requirements.

*Soft*Risk has nine emergency management features:

1. Question Tree

The purpose of the Question Tree is to define the major characteristics of an emergency so that ***Soft*Risk** can automatically generate prioritized response information. The Question Tree consists of a series of related questions and menus that identify specific hazards or types of emergencies present in any jurisdiction. When all the questions needed to outline a specific emergency have been answered, ***Soft*Risk** will display the relevant Emergency Response Information. ***Soft*Risk** accommodates complex or multiple emergencies by allowing the selection of more than one emergency in the Question Tree. The Question Tree can be configured and amended by the user to reflect any number of hazards.

2. Emergency Response Information

Emergency Response Information provides the pertinent prioritized contact lists and response procedures needed to respond to an emergency as quickly and efficiently as possible. Emergency Response Information consists of a Priority Contact List, Response Procedures, and a Question Tree Response.

3. Maps

***Soft*Risk's** Maps provide accurate, interactive maps for a variety of practical emergency management applications. All kinds of valuable data can be associated with the Maps and quickly retrieved. For example, hazardous, sensitive, and resource sites can be designated on the Maps using icons. Similarly, evacuation centres and routes, pipelines, flood zones, rail lines, and road closures - to name a few - can also be depicted. ***Soft*Risk's** Maps enable quick zooming down to a street address or coordinate, scrolling around 360 degrees, access to site and route information, the drawing of emergency areas, finding streets and coordinates, drawing routes, and graphically displaying the deployment of resources. ***Soft*Risk**'s Maps also enable the conversion of GIS maps, significantly enhancing their utility in terms of information access.

4. Log

The Log provides the means of keeping date/time stamped records of events. Decisions and actions, resource allocations, and communications executed during an emergency or exercise are automatically recorded for debriefing, documentation and reference purposes.

5. Database

***Soft*Risk** incorporates a powerful relational database capability enabling users to efficiently manage records on contacts, resources, and sites. Furthermore, ***Soft*Risk** users have the ability to query the database in a wide variety of useful ways. The relational database feature makes it possible to run the software on local area networks (**LAN**) and over a wide area (**WAN**). It has an open architecture enabling the importation of files from various sources.

6. Supporting Plans

The purpose of Supporting Plans is to provide a means for storing and communicating supplementary emergency planning information, such as Communications Plans, Evacuation Plans, Responsibilities, Standard Operating Procedures, etc. This feature of ***Soft*Risk** is totally flexible and easily configured by the user. Supporting Plans can take advantage of text, graphics, and maps in virtually any format.

7. Fax Management

Fax Management enables the viewing, printing, and re-faxing of received faxes and file transfers, the communication of non-***Soft*Risk** text and graphics information to other computers or fax machines, and the managing of the communications co-processor. Sending a fax of ***Soft*Risk** graphics or text is done simply by pressing the fax button on the appropriate screen.

8. Information Management

Information Management consists of a full range of configuration programs that enable the user to add, edit, or delete data that is stored in ***Soft*Risk**. This feature enables users to tailor ***Soft*Risk** to suit any organization's requirements.

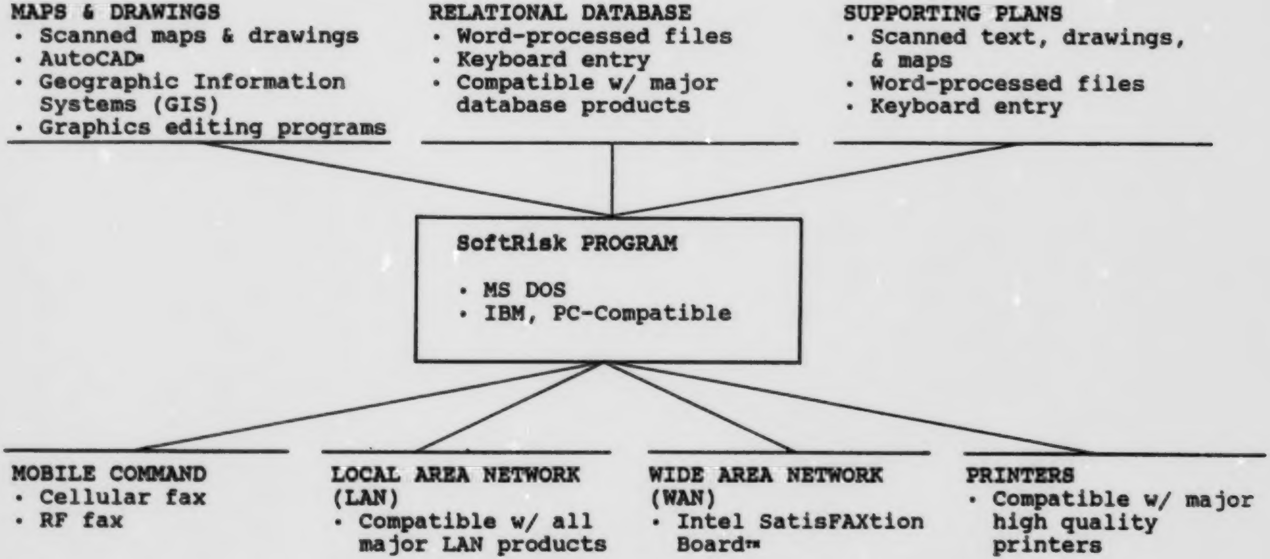
9. Appendices

The Appendices provide a number of functions to assist in the understanding and operation of ***Soft*****Risk**. The Interactive Tutorial is designed to support individuals tasked with learning how to operate the software. The purpose of Other ***SoftRisk*** Operations is to supply the functions needed to keep other features of ***Soft*****Risk** up-to-date.

IV. IMPACT RESEARCH GROUP LTD.

As a research and development company, Impact specializes in managing risks to public health and safety, property, and the environment. Corporate personnel have practical, hands-on emergency planning and response experience as well as a high level of technical expertise. The company was incorporated on June 11, 1985.

SoftRisk COMPATIBILITY


MAPS & DRAWINGS
• Scanned maps & drawings
• AutoCAD®
• Geographic Information Systems (GIS)
• Graphics editing programs
RELATIONAL DATABASE
• Word-processed files
• Keyboard entry
• Compatible w/ major database products
SUPPORTING PLANS
• Scanned text, drawings, & maps
• Word-processed files
• Keyboard entry
SoftRisk PROGRAM
• MS DOS
• IBM, PC-Compatible
MOBILE COMMAND
• Cellular fax
• RF fax
LOCAL AREA NETWORK (LAN)
• Compatible w/ all major LAN products
WIDE AREA NETWORK (WAN)
• Intel SatisFAXtion Board™
PRINTERS
• Compatible w/ major high quality printers

A COMPUTERIZED EQUIPMENT AND PERSONNEL MANAGEMENT SYSTEM SPECIFIC TO OIL SPILL RESPONSE

by

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ABSTRACT

Alaska Clean Seas (ACS) recently implemented a computerized and integrated equipment and personnel management system for oil spill response. This system was derived from a commercially available program that was specifically for maintenance management of college campuses. ACS acquisition of the program was with the knowledge that the program could be customized by working closely with the developer.

Over an approximate five month period ACS proceeded to customize the program to make it specific to oil spill response. Features include:

- detailed and summary level spill equipment inventories
- preventive maintenance schedules for spill equipment
- spare parts control for all equipment
- database of spill response personnel and their training
- integrated spill packages based on a major tag number
- work order system for maintenance cost tracking

An important additional aspect of the software package is its ability to incorporate spill response equipment from outside sources. With the development of a three level hierarchy that specifies owner, location, and area, the program can integrate but separate equipment and personnel data from not only ACS operations but other North Slope operators. This aspect alone offers tremendous potential for spill response organizations to track not only their own but other resources in an actual spill response.

The implementation of this database provides ACS with a relatively inexpensive and user friendly system which includes the often under estimated aspect of spill response equipment maintenance.

INTRODUCTION

Alaska Clean Seas is the oil spill response cooperative for Alaska's North Slope oil exploration, production, and pipeline operations as well as Alaska North and West coast offshore exploration activities. Current members of the cooperative include all major oil exploration, production, and pipeline operators in Alaska. ACS provides manpower and equipment to respond to an oil spill. In addition, training, research and development, and contingency planning is carried out on behalf of its member companies.

In 1990 ACS was restructured from an equipment co-op into a full response organization. It is now organized to respond to an emergency with both trained people and equipment.

With the restructuring of ACS and a significant increase in inventory came the need for a computerized maintenance management system for oil spill response equipment. The following is a list of the required needs of the system:

- Inventory control
- Parts control
- Work order generation
- Preventive maintenance scheduling
- Dual platform capabilities
- Cost tracking
- Personnel database
- Adaptability

The purchase and subsequent customization provided the above system components.

COMPUTER SYSTEM

Software

The spill response equipment management system is written in Omnis 5. Omnis 5 is a versatile database applications generator tool designed to give developers the ability to change applications with a minimum of time and expense. The software is an application that was developed primarily for facility maintenance of college campuses. ACS took the inherent database and maintenance modules and developed a software package specific to oil spill response. The report generator is left available for custom report generation. This feature has allowed ACS to develop equipment analysis reports, summary reports, and various combinations of reports relative to spill response equipment.

Hardware

ACS retains both Macintosh and DOS computers, however it primarily uses Macintosh equipment. The program is multi-user and thus runs on a local area network (LAN). At present time ACS runs the database program on an Apple Local Talk network with three workstations and a 140 Meg fileserver at its North Slope Spill Response Center. The datafile is stored on the fileserver and the program is on each workstation. The multiuser capability of the program allows simultaneous access to different records in the program.

Through the use of a telebridge and modem the North Slope datafile is electronically transferred to the Anchorage office on a periodic basis for equipment and cost analysis.

An important consideration for the program is its ability to run on both Macintosh and IBM compatible machines. The Omnis database was initially developed on DOS machines and the program is inherently dual platform capable.

PROGRAM LOGIC

The spill response software consists of five main modules:

- SPILL RESPONSE EQUIPMENT
- WORK ORDERS
- SPILL RESPONSE PERSONNEL
- PREVENTIVE MAINTENANCE
- PARTS

These modules function independently of each other, but are directly linked through various fields. These links are accomplished through the relational database functions of Omnis 5. Figure (1) is a graphical representation of the modules.

LOGIC DIAGRAM

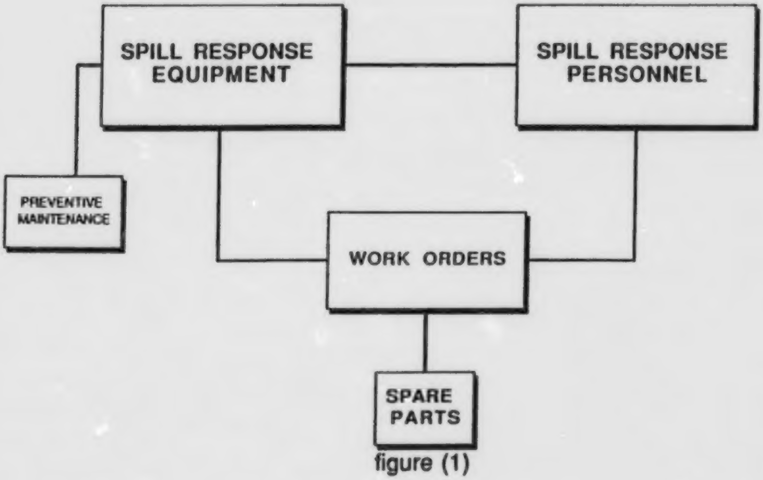


figure (1)

The two prominent modules in terms of spill response are the Spill Response Equipment and Spill Response Personnel. As noted from the logic diagram both the spill response equipment module and the spill response personnel module tie directly into the work order modules. The work order module allows ACS to monitor both labor and materials cost for:

- Personnel training
- Equipment maintenance
- Facilities maintenance
- Third party service control
- Spill expenses

Also tied to the work orders is the spare parts module. This module provides ACS with a parts inventory tracking and movement system. Finally the preventive maintenance module allows ACS to schedule and keep track of PM requirements for spill response equipment.

SPILL RESPONSE EQUIPMENT

The program allows ACS to maintain a complete inventory of all pertinent information relative to spill response equipment. One of the key features in the system of spill equipment tracking is the Owner Location Area designation (OLA number). This OLA number allows ACS to database not only its own equipment but also that of its owner companies and potentially spill response equipment from other regions in the world. The OLA number provides an identification for each piece of equipment that allows ACS to locate the equipment , and if desired provide cost tracking and maintenance scheduling for each owner. The OLA number is a three level hierarchy that locates each piece of equipment to a specific area, then to a location and finally to a specific owner. Figure (2) shows the OLA hierarchy.

OLA NUMBER LOGIC FLOW

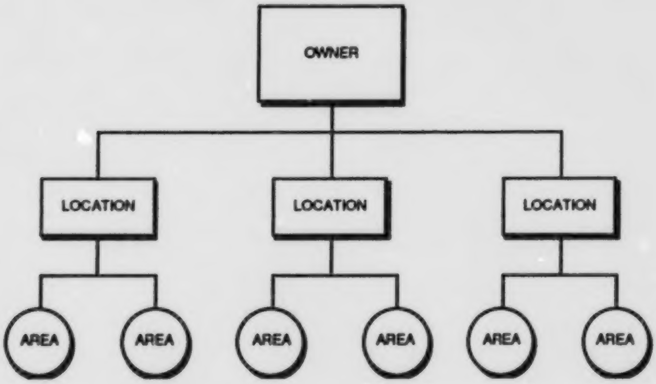


figure (2)

The following is an example of an ACS OLA number:

ACS-DH-70

This number indentifies Alaska Clean Seas as the specific owner, Deadhorse, Alaska as the location, and the numerical designation of 70 as the ACS Deadhorse Spill Response Center warehouse in Deadhorse.

EQUIPMENT INFORMATION

ACS uses a total of three screens to maintain all information on each individual piece of response equipment. The first entry field in screen 1 allows an equipment tag number to be attached to each piece of equipment. The equipment tag system consists of a 10 digit number.

EQUIPMENT TYPE		ITEM NUMBER		SUFFIX (OPTIONAL)
XXXX	-	XXXX	-	XX

EQUIPMENT TYPE FIELD

The equipment type field is a four digit alpha field that specifies the equipment type. This alpha code provides persons with specific information on the piece of equipment. The following is a list of the 4 digit alpha code associated with boom:

BMSB	BOOM, SORBENT
BMDT	BOOM, DELTA
BMFX	BOOM, FIRE
BMHB	BOOM, HARBOR
BMOC	BOOM, OCEAN
BMRV	BOOM, RIVER
BMSH	BOOM, SHORE SEAL

The first two characters indentify the equipment as boom and the second two characters identifies the type of boom.

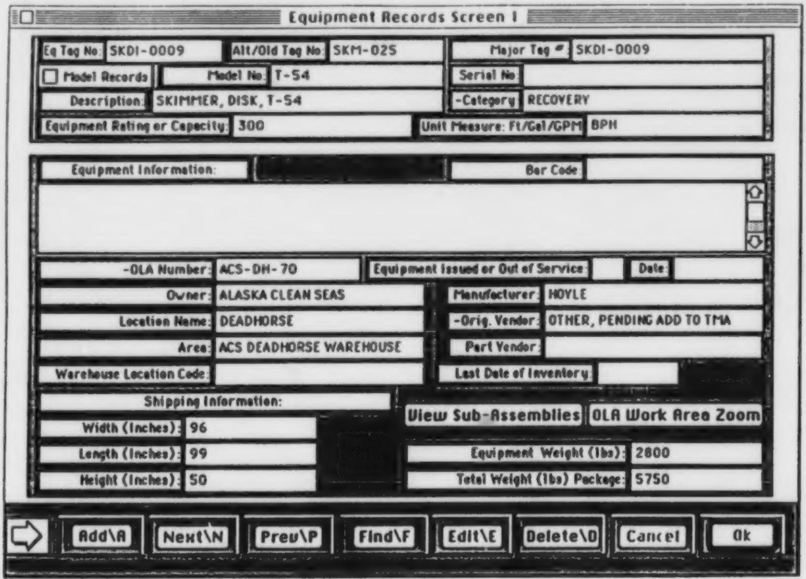
ITEM NUMBER FIELD

The item number field is a 4 - digit numerical field that identifies the specific item. Equipment types are further identified, where applicable, by manufacturer, size, or capacities by the use of the first and/or second digit to create a series.

SUFFIX FIELD

The suffix field contains a 2 - digit alpha numeric field that is used in the event of a duplicate tag number or to add a useful detail about a type of equipment.

SCREEN 1 ENTRY WINDOW



Eq Tag No: SKDI-0009
Alt/Old Tag No: SKM-025
Major Tag #: SKDI-0009
☐ Model Records
Model No: T-54
Serial No:
Description: SKIMMER, DISK, T-54
-Category: RECOVERY
Equipment Rating or Capacity: 300
Unit Measure: Ft/Gal/GPM: BPH
Equipment Information:
Bar Code:
-OLA Number: ACS-DH-70
Equipment Issued or Out of Service:
Date:
Owner: ALASKA CLEAN SEAS
Manufacturer: HOYLE
Location Name: DEADHORSE
-Orig. Vendor: OTHER, PENDING ADD TO TMA
Area: ACS DEADHORSE WAREHOUSE
Part Vendor:
Warehouse Location Code:
Last Date of Inventory:
Shipping Information:
Width (Inches): 96
Length (Inches): 99
Height (Inches): 50
Equipment Weight (lbs): 2800
Total Weight (lbs) Package: 5750

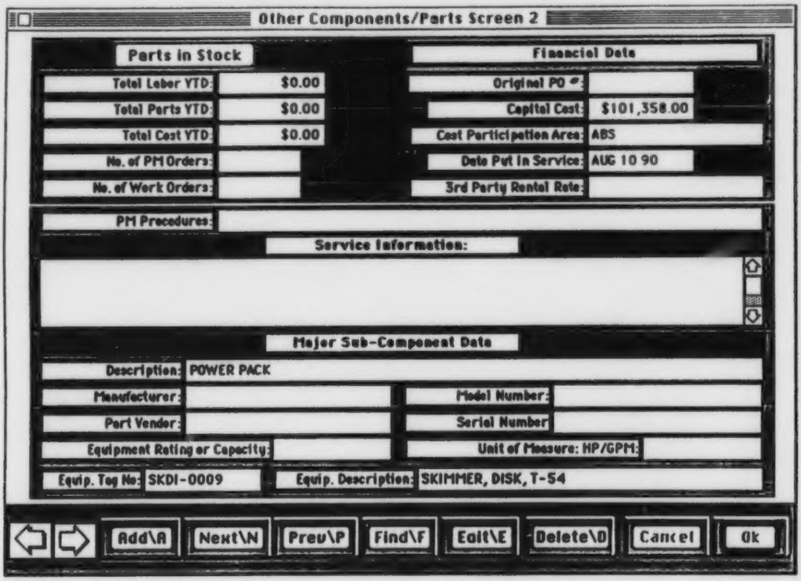
figure (3)

Figure (3) is screen 1 in the equipment module. The associated fields allow ACS to attach the required information shown in each field. The buttons on the bottom provide the data entry functions at the click of a mouse.

Major Tag #

The major tag # field is a provision developed by ACS that allows the database to subordinate other pieces of equipment to a common major tag #. This major tag # allows ACS to program a package generation report which facilitates the extraction of spill response packages from the equipment file. Once in the package selection screen the operator simply clicks on the package icon and the program locates the common major tag # and produces a spill package. This spill equipment package report shows all subordinate equipment that goes with the main piece of equipment. Also on the report is the shipping dimensions and shipping weights of each piece of equipment. The total shipping weight of the package is also displayed.

SCREEN 2 ENTRY WINDOW



Other Components/Parts Screen 2

Parts in Stock

Total Labor YTD: $0.00
Total Parts YTD: $0.00
Total Cost YTD: $0.00
No. of PM Orders:
No. of Work Orders:

Financial Data

Original PO #:
Capital Cost: $101,358.00
Cost Participation Area: ABS
Date Put In Service: AUG 10 90
3rd Party Rental Rate:

PM Procedures:

Service Information:

Major Sub-Component Data

Description: POWER PACK
Manufacturer:
Model Number:
Part Vendor:
Serial Number
Equipment Rating or Capacity:
Unit of Measure: HP/GPM:
Equip. Tag No: SKDI-0009
Equip. Description: SKIMMER, DISK, T-54

figure (4)

Equipment entry screen 2, figure (4), shows both required entry fields and calculated fields. The fields in the upper left of the screen display the total year to date costs associated with that piece of equipment. Also the number of work orders and PM work orders associated with that piece of equipment are displayed. Financial data and sub-component parts fields are also available.

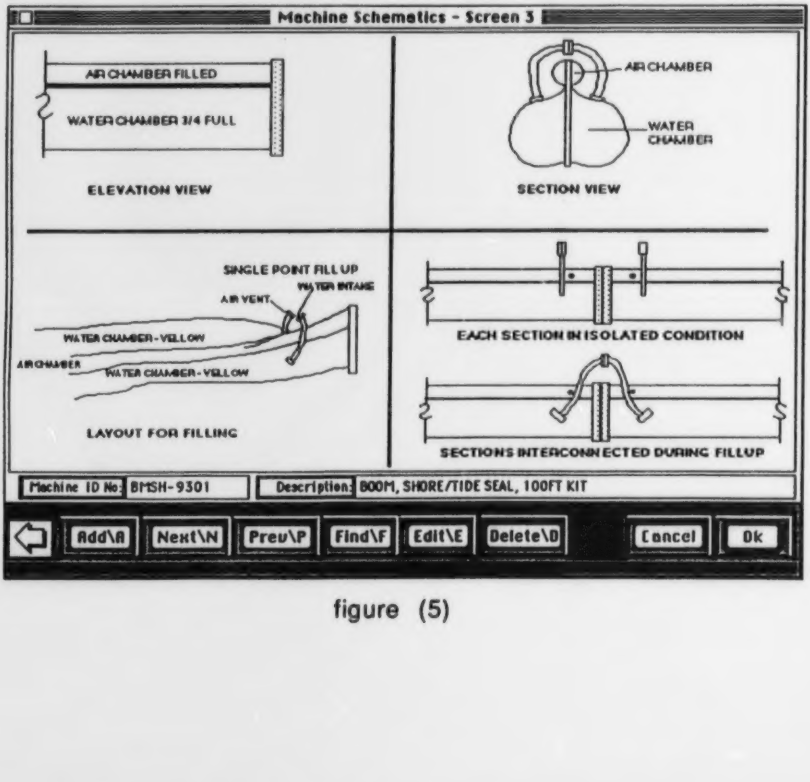
These two screens contain all the information required by ACS to keep track of and manage both ACS and member companies equipment. The equipment screens are designed in a logical order and provide for a simple user friendly interface.

PARTS IN STOCK

The Parts in Stock button gives the user the ability click on the button and produce a report that shows all associated parts in stock for that particular piece of equipment.

Screens 1 and 2 provide all entry fields ACS uses to keep track of and maintain both ACS and member companies spill response equipment. These fields are used to generate numerous combinations of custom reports.

EQUIPMENT SCREEN 3


Machine Schematics - Screen 3
AIR CHAMBER FILLED
WATER CHAMBER 3/4 FULL
ELEVATION VIEW
AIR CHAMBER
WATER CHAMBER
SECTION VIEW
SINGLE POINT FILL UP
WATER INTAKE
AIR VENT
WATER CHAMBER - YELLOW
AIR CHAMBER
WATER CHAMBER - YELLOW
LAYOUT FOR FILLING
EACH SECTION IN ISOLATED CONDITION
SECTIONS INTERCONNECTED DURING FILLUP
Add\A
Next\N
Prev\P
Find\F
Edit\E
Delete\D
Cancel
Ok

Machine ID No: BMSH-9301

Description: BOOM, SHORE/TIDE SEAL, 100FT KIT

figure (5)

Equipment screen 3 figure (5) provides ACS with the ability to attach a graphic entry to each piece of equipment. This screen can be used to show a full representation of a piece of equipment, a key schematic, or perhaps a boom connection scheme.

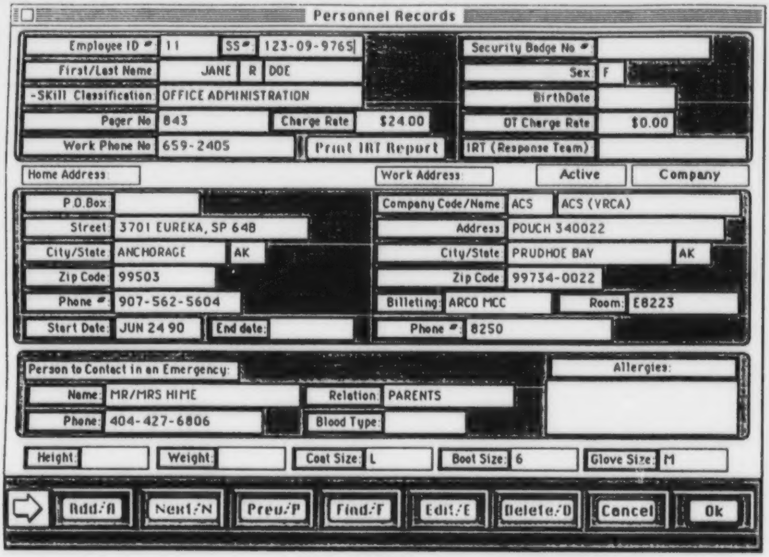
SPILL RESPONSE PERSONNEL

The Spill Response Personnel module allows ACS to maintain data on ACS employees as well as member company Immediate Response Teams (IRT), Village Response Teams (VRT), and Auxiliary Contractor Teams (ACT). The module is made up of two screens that allow all required data entry for personnel. Screen 1 figure (6) of this module allows ACS to attached three different addresses to each individual. ACS can also assign phone numbers and beeper numbers to each entry. Fields for appropriate clothing sizes are also provided.

An important feature of the ACS personnel tracking system is the training files on screen 2 figure (7). Each individual in the system has all of his/her training entered into the system. Attached to each individual is additional skills such as mechanic, boat operator, etc.. This information allows ACS to search the database for various skill and training criteria. In the event of a spill, ACS has all pertinent information to locate and notify key personnel. To aid in the scheduling of training, the program provides a search criteria selection that allows ACS to ask for all individuals whose certificates expire at a selected date. After a course and expiration date are entered, the program can identify all individuals whose selected class certification expires before the given date. Finally the personnel module provides an entry field for a scanned photograph of the individual.

This database of information insures that qualified and correctly trained individuals are available in the event of a spill.

PERSONNEL SCREEN 1



Personnel Records
Print IRT Report
Home Address:
Work Address:
Active
Company
Add/A
Next/N
Prev/P
Find/F
Edit/E
Delete/D
Cancel
Ok

Employee ID #: 11
SS#: 123-09-9765
Security Badge No #:
First/Last Name: JANE R DOE
Sex: F
-Skill Classification: OFFICE ADMINISTRATION
BirthDate:
Pager No: 843
Charge Rate: $24.00
OT Charge Rate: $0.00
Work Phone No: 659-2405
IRT (Response Team):

P.O.Box:
Street: 3701 EUREKA, SP 648
City/State: ANCHORAGE AK
Zip Code: 99503
Phone #: 907-562-5604
Start Date: JUN 24 90
End date:

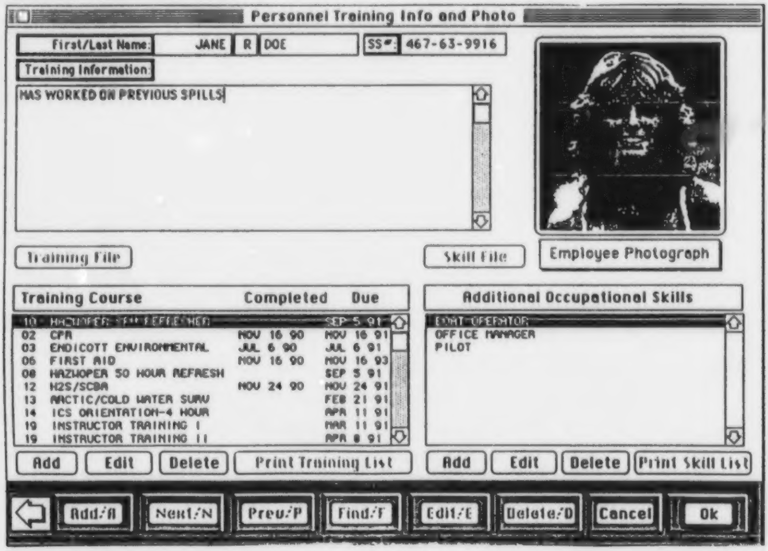
Company Code/Name: ACS ACS (VRCA)
Address: POUCH 340022
City/State: PRUDHOE BAY AK
Zip Code: 99734-0022
Billeting: ARCO MCC
Room: E8223
Phone #: 8250

Person to Contact in an Emergency:
Name: MR/MRS HIME
Relation: PARENTS
Phone: 404-427-6806
Blood Type:
Allergies:

Height:
Weight:
Coat Size: L
Boot Size: 6
Glove Size: M

figure (6)

PERSONNEL SCREEN 2



Personnel Training Info and Photo
Training File
Skill File
Employee Photograph
Add
Edit
Delete
Print Training List
Add
Edit
Delete
Print Skill List
Add/A
Next/N
Prev/P
Find/F
Edit/E
Delete/D
Cancel
Ok

First/Last Name: JANE R DOE
SS#: 467-63-9916
Training Information:

HAS WORKED ON PREVIOUS SPILLS

Training Course		Completed	Due
10	HAZWOPER [illegible] REFRESHER		SEP 5 91
02	CPR	NOV 16 90	NOV 16 91
03	ENDICOTT ENVIRONMENTAL	JUL 6 90	JUL 6 91
06	FIRST AID	NOV 16 90	NOV 16 93
08	HAZWOPER 50 HOUR REFRESH		SEP 5 91
12	H2S/SCBA	NOV 24 90	NOV 24 91
13	ARCTIC/COLD WATER SURV		FEB 21 91
14	ICS ORIENTATION-4 HOUR		APR 11 91
19	INSTRUCTOR TRAINING I		MAR 11 91
19	INSTRUCTOR TRAINING II		APR 8 91

Additional Occupational Skills

BOAT OPERATOR
OFFICE MANAGER
PILOT

figure (7)

WORK ORDERS

The work order system, figure (9), provides the capability of monitoring maintenance and labor costs. The system allows the compilation of data to provide information such as:

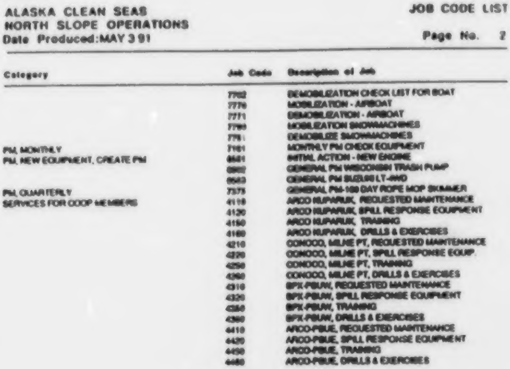
- Total parts cost on a specific piece of equipment
- Total labor cost on a specific piece of equipment
- Number and type of work orders generated on equipment

The work order system has provisions for cost tracking based on the OLA number. This enables ACS to monitor costs associated with a particular owners equipment on which ACS may be carrying out preventive maintenance. Historical data can be extracted based on any selected duration of time.

JOB CATEGORIES

During the initial set-up of the software, job categories are entered into the system as shown figure (8). Each job category has a range of job codes. These job codes are assigned to each work order generated. The assigning of a job code to each work order enables costs to be monitored for each type of work completed. An estimated time field within the work orders drives a work order backlog report, figure (10), associated with each job code. This report can be generated for any specified duration of time i.e. week, month, year, etc.. This particular report is a tremendous planning tool for the allocation of resources.

JOB CODE LIST



ALASKA CLEAN SEAS
NORTH SLOPE OPERATIONS
Date Produced:MAY 3 91

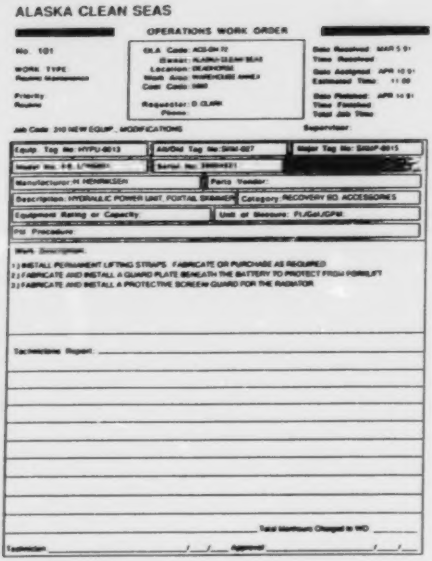
JOB CODE LIST

Page No. 2

Category	Job Code	Description of Job
	7702	DEMOBILIZATION CHECK LIST FOR BOAT
	7770	MOBILIZATION - AIRBOAT
	7771	DEMOBILIZATION - AIRBOAT
	7780	MOBILIZATON SNOWMACHINES
	7781	DEMOBILIZE SNOWMACHINES
PM, MONTHLY	7101	MONTHLY PM CHECK EQUIPMENT
PM, NEW EQUIPMENT, CREATE PM	8581	INITIAL ACTION - NEW ENGINE
	8582	GENERAL PM WISCONSIN TRASH PUMP
	8583	GENERAL PM SUZUKI LT-4WD
PM, QUARTERLY	7575	GENERAL PM-180 DAY ROPE MOP SKIMMER
SERVICES FOR COOP MEMBERS	4110	ARCO KUPARUK, REQUESTED MAINTENANCE
	4120	ARCO KUPARUK, SPILL RESPONSE EQUIPMENT
	4150	ARCO KUPARUK, TRAINING
	4160	ARCO KUPARUK, DRILLS & EXERCISES
	4210	CONOCO, MILNE PT, REQUESTED MAINTENANCE
	4220	CONOCO, MILNE PT, SPILL RESPONSE EQUIP.
	4250	CONOCO, MILNE PT, TRAINING
	4260	CONOCO, MILNE PT, DRILLS & EXERCISES
	4310	BPX-PBUW, REQUESTED MAINTENANCE
	4320	BPX-PBUW, SPILL RESPONSE EQUIPMENT
	4350	BPX-PBUW, TRAINING
	4360	BPX-PBUW, DRILLS & EXERCISES
	4410	ARCO-PBUE, REQUESTED MAINTENANCE
	4420	ARCO-PBUE, SPILL RESPONSE EQUIPMENT
	4450	ARCO-PBUE, TRAINING
	4460	ARCO-PBUE, DRILLS & EXERCISES

figure (8)

ISSUE WORK ORDER



ALASKA CLEAN SEAS

OPERATIONS WORK ORDER

No. 101

WORK TYPE
Routine Maintenance

Priority
Routine

OLA Code: ACS-DH-72
Owner: ALASKA CLEAN SEAS
Location: DEADHORSE
Work Area: WAREHOUSE ANNEX
Cost Code: [illegible]

Requestor: D. CLARK
Phone:

Date Received: MAR 5 91
Time Received:
Date Assigned: APR 10 91
Estimated Time: 11.00
Date Finished: APR 14 91
Time Finished:
Total Job Time:

Job Code: 310 NEW EQUIP., MODIFICATIONS

Supervisor:

Equip. Tag No: HYPU-0013	Alt/Old Tag No: [illegible]	Major Tag No: SKIMP-0015
Model No: [illegible]	Serial No: [illegible]	[redacted]
Manufacturer: H. HENRIKSEN	Parts Vendor:	
Description: HYDRAULIC POWER UNIT, PORTABLE SKIMMER	Category: RECOVERY EQ. ACCESSORIES	
Equipment Rating or Capacity:	Unit of Measure: Ft./Gal./GPM	
PM Procedure:		

Work Description:

1.) INSTALL PERMANENT LIFTING STRAPS. FABRICATE OR PURCHASE AS REQUIRED
2.) FABRICATE AND INSTALL A GUARD PLATE BENEATH THE BATTERY TO PROTECT FROM FORKLIFT
3.) FABRICATE AND INSTALL A PROTECTIVE SCREEN GUARD FOR THE RADIATOR

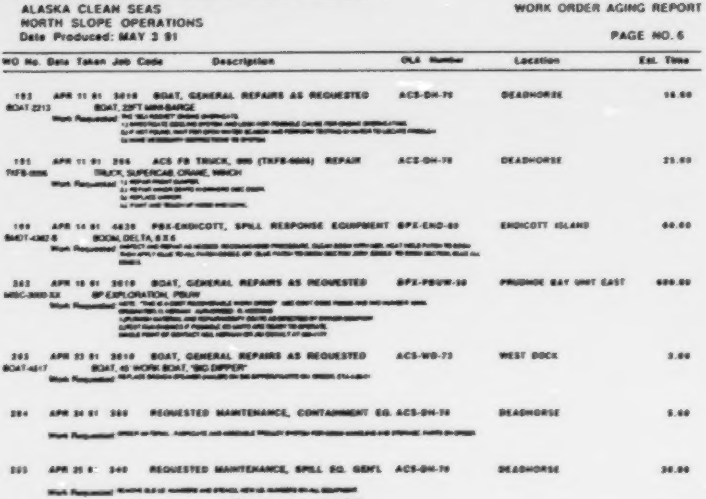
Technicians Report: ____

Total Manhours Charged to WO ____

Technician ____ /__/__ Approved ____ /__/__

figure (9)

WORK ORDER BACK LOG REPORT



```
ALASKA CLEAN SEAS                                          WORK ORDER AGING REPORT
NORTH SLOPE OPERATIONS
Date Produced: MAY 3 91                                    PAGE NO. 6

WO No. Date Taken Job Code   Description                  OLA Number     Location              Est. Time

 192   APR 11 91  3010  BOAT, GENERAL REPAIRS AS REQUESTED    ACS-DH-70   DEADHORSE                 16.00
BOAT 2213        BOAT, 22FT MINI-BARGE
      Work Requested [illegible]

 191   APR 11 91  266   ACS FB TRUCK, 006 (TKFB-0006) REPAIR  ACS-DH-70   DEADHORSE                 25.00
TKFB-0006        TRUCK, SUPERCAB, CRANE, WINCH
      Work Requested [illegible]

 199   APR 14 91  4630  PBX-ENDICOTT, SPILL RESPONSE EQUIPMENT BPX-END-60 ENDICOTT ISLAND           60.00
BMDT-4362-B      BOOM, DELTA, 6 X 6
      Work Requested [illegible]

 202   APR 18 91  3010  BOAT, GENERAL REPAIRS AS REQUESTED    BPX-PBUW-30 PRUDHOE BAY UNIT EAST    600.00
MISC-3000-XX     BP EXPLORATION, PBUW
      Work Requested [illegible]

 203   APR 23 91  3010  BOAT, GENERAL REPAIRS AS REQUESTED    ACS-WD-73   WEST DOCK                  3.00
BOAT-4517        BOAT, 40' WORK BOAT, "BIG DIPPER"
      Work Requested [illegible]

 204   APR 24 91  360   REQUESTED MAINTENANCE, CONTAINMENT EQ. ACS-DH-70  DEADHORSE                  5.00

      Work Requested [illegible]

 205   APR 25 91  340   REQUESTED MAINTENANCE, SPILL EQ. GENL ACS-DH-70   DEADHORSE                 30.00

      Work Requested [illegible]
```

figure (10)

SPARE PARTS

An important component of an effective maintenance program is an organized spare parts system. Parts are entered under discrete categories. The part entry screen has provisions for:

Description
Manufacturer
Minimum level
Maximum level
Quantity on hand
Vendor

The program requires that an individual use an inventory adjustment sheet to add or subtract parts from stock.

PREVENTIVE MAINTENANCE

The preventive maintenance module provides the ability to schedule maintenance of spill response equipment. To create a PM schedule for a machine the operator first specifies the equipment tag number. A PM job category is then selected. After the PM jobs for that piece of equipment are established the user then selects the required frequency of the job. The program generates the following PM reports:

- PM work orders open
- PM work orders complete
- PM work orders all
- PM scheduled next day
- PM scheduled next 7-days
- PM scheduled next 30-days

The preventive maintenance module insures that ACS maintains spill response equipment in the maximum state of readiness in the event of a required response.

CONCLUSION

The implementation of this spill response computerized database and personnel system helps ACS provide effective management of spill response equipment. In the future spill response organizations will maintain more and more equipment. As the value of capital inventories increase so to does the need for a more sophisticated management and maintenance system. An effective and rapid response is directly related to the condition and logistical control of response equipment. The multi-platform capability of this program allows the system to meet multi-company needs regardless of the type of PC. The customization capabilities of the program were the key to the successful development of a maintenance system specific to spill response. This customization feature allows the system to be expanded as the need arises.

ENDNOTE

Throughout this paper, reference has been made to specific hardware and software brands and models. These references are for information, only, and do not constitute an endorsement of such hardware or software, nor do they imply that other hardware and software cannot be utilized for purposes of computerized management.

REFERENCES

OMNIS 5 APPLICATION DESIGNERS HANDBOOK, Blyth Software Inc., 1065 E. Hillsdale Blvd #300 Foster City, CA

Gary R. Schaecher, TMA The Maintenance Authority, TMA Systems, 8212 South Harvard, Tulsa, Oklahoma

IMPLEMENTATION OF THE
INCIDENT COMMAND SYSTEM
ON THE ALASKAN NORTH SLOPE

by

Bruce McKenzie
Alaska Clean Seas
P.O. Box 196010
Anchorage, AK 99519-6010

Abstract

To meet self imposed improvements of its spill response capability and also comply with stringent State and Federal regulatory requirements, the Alaskan North Slope oil industry operators have implemented a common Incident Command System (ICS) on the North Slope. The structure of the Incident Command System was based directly on the National Interagency Incident Management System (NIIMS), originally developed for responding to wildland fires. Work done in the past two years by Alyeska Pipeline Service Company (Alyeska), the first to adopt ICS for spill response, was also closely reviewed and used as an initial basis. A comprehensive training program has been developed for implementation of the system on the North Slope.

Introduction

The March 24, 1989 grounding of the *Exxon Valdez* was a catalyst for the oil industry throughout North America to review its spill response capability and preparedness. This was particularly true for those members of the oil industry operating within the State of Alaska.

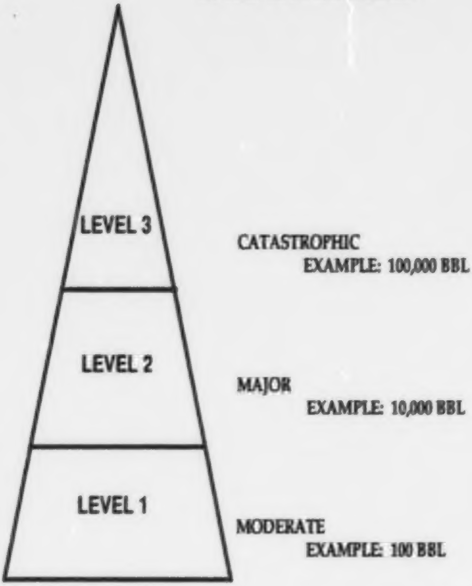
Immediately following the Valdez grounding, Alaskan North Slope operating companies recognized the need to critically review their oil spill response capability. With the concurrence of executive management, a steering committee was formed to review the North Slope response capability and ensure that an adequate spill response infrastructure was in place. The committee was comprised of representatives of the following North Slope industry operators:

Alyeska Pipeline Service Company
ARCO - Kuparuk
ARCO - Prudhoe Bay
BP - Prudhoe Bay
BP - Endicott
Conoco - Milne Point

This review resulted in a significant reorganization of the spill response infrastructure on the North Slope. The reorganization was based on a tiered response, recognizing the need to transition from one level of spill to the next. This tiered response is outlined in *Figure 1* and is briefly described below.

FIGURE 1

SPILL CATEGORIES



For a Level 1 spill (nominally identified at 100 bbls.) each Operator has the capability to respond, contain and cleanup the spill with its own Initial Response Team (IRT). For a Level 2 or major spill (nominally identified in the range of 10,000 bbls.) a spiller calls upon mutual aid from the other North Slope operator's IRTs and also Alaska Clean Seas (ACS). ACS' mission has been expanded from an oil spill equipment Co-op to an oil spill response Cooperative. In addition, its geographic area of responsibility was expanded to include onshore activities on the North Slope as far south as the Brooks Range. ACS now has sufficient resources and manpower to deal with a Level 2 spill. Upon an initial call out, contract provisions exist to provide 50 trained personnel within 4 hours. In addition, another 140 personnel from Anchorage and North Slope communities are available within 24 hours. Contracts are in place to provide 500 people within a week.

For a Level 3 catastrophic type spill (in the range of 100,000 bbls.) the process would be similar to that described for the major spill. Additional personnel would be mobilized from contract sources with the potential for supplying of the order of 5,000 individuals within one month. *Table 1* outlines the primary responder on the North Slope for varying sizes of spills.

TABLE 1

NORTH SLOPE RESPONSE STRATEGY

PRIMARY RESPONDER IDENTIFICATION

	Hour 1	**Hour 8**	**Hour 48**
1 (Moderate)	**IRT**	**IRT**	**IRT**
2 (Major)	**IRT**	**IRT** **Mutual Aid** **ACS**	**ACS**
3 (Catastrophic)	**IRT**	**IRT** **Mutual Aid** **ACS**	**ACS** **Contractor**

The volumes used to define the three levels of response are subjective. The point at which a spiller may go to a Level 2 or 3 response will vary according to the resources available to each Operator as well as the time of year and nature of the spill. Similarly, any Operator can call for assistance from ACS for a level I spill if necessary.

The Steering Committee recognized that for the mutual aid concept to work, a common response structure would need to be in place for the North Slope. This structure needed to provide uniformity of organization and terminology among all mutual aid teams, ACS and it's auxiliary contractor and village response teams. This would allow dissimilar organizations to function effectively in a multi-organizational environment.

This recognized need for a common response structure was reinforced by the implementation of Alaska State Statute AS46.04.030(K), commonly known as HB 567 (1990). Under this law, the holder of an approved contingency plan is required to have sufficient resources available to "contain or control, and clean up the realistic maximum oil discharge within 72 hours". It was recognized by the North Slope Operators that to meet this planning standard an organizational structure that allowed for rapid response escalation needed to be implemented.

The decision on which organizational structure would be implemented was made concurrent with development and evaluation of federal and state statutes. The United States Federal Occupational Safety and Health Administration (OSHA) requires that personnel responding to hazardous materials spills understand and utilize the Incident Command System in their response. The same holds true for the State of Alaska Occupational Safety and Health Standards for hazardous waste operation and emergency response; both their existing regulations and their new proposed regulations.

The recognition of the need for a common system, the planning standards of HB567 and the OSHA requirements provided the additional impetus needed for the implementation of an Incident Command System on the North Slope for oil spill response. Alaska Clean Seas was tasked with the job of developing the ICS model for the North Slope Operators. This was done with input from operational spill personnel as well as middle and senior management up to the Field Manager level.

Alaska North Slope ICS Structure

The ICS structure chosen for implementation on the North Slope is shown in *Figure 2*. This structure was based directly on the National Interagency Incident Management System (NIIMS) developed for use by fire protection agencies (see *Figure 3)*. Modifications initiated by Alyeska Pipeline Service Company for implementation of the ICS system for spill response in Prince William Sound were also factored into the process (*Figure 4*).

In developing the system for the North Slope the NIIMS structure was used as a basic building block and the work done by Alyeska was carefully reviewed for applicability on the North Slope. With some slight variations discussed below, the Alyeska structure was chosen for implementation.

For the North Slope, the Operations component of the ICS was left intentionally unstructured. The organization is shown to be broken into divisions or groups, but their exact role is undefined. Due to the wide range of operations that take place on the North Slope (exploration, production, transportation) as well as the large geographical area of coverage (onshore, offshore, rivers and tundra) there is a large number of potential spill scenarios that could be developed. This is further complicated when spill response options, resources potentially at risk and other components of a possible emergency are factored into the equation.

FIGURE 2

NORTH SLOPE ICS STRUCTURE

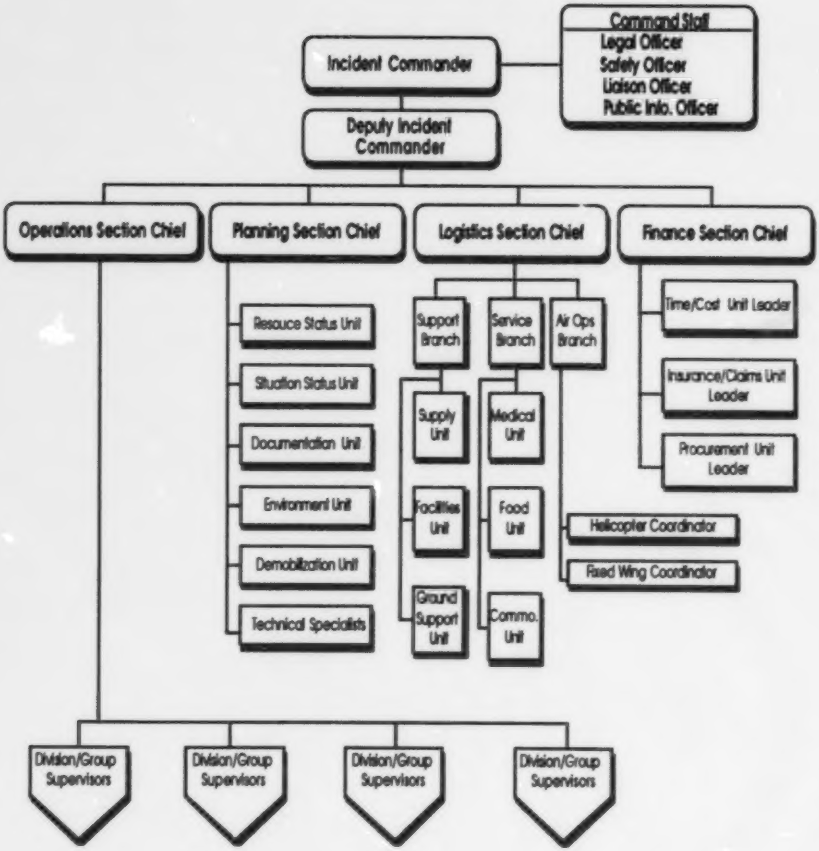

Command Staff
Legal Officer
Safety Officer
Liaison Officer
Public Info. Officer
Incident Commander
Deputy Incident Commander
Operations Section Chief
Planning Section Chief
Logistics Section Chief
Finance Section Chief
Resouce Status Unit
Situation Status Unit
Documentation Unit
Environment Unit
Demobilization Unit
Technical Specialists
Support Branch
Service Branch
Air Ops Branch
Supply Unit
Facilities Unit
Ground Support Unit
Medical Unit
Food Unit
Commo. Unit
Helicopter Coordinator
Fixed Wing Coordinator
Time/Cost Unit Leader
Insurance/Claims Unit Leader
Procurement Unit Leader
Division/Group Supervisors
Division/Group Supervisors
Division/Group Supervisors
Division/Group Supervisors

FIGURE 3

NIIMS ICS STRUCTURE

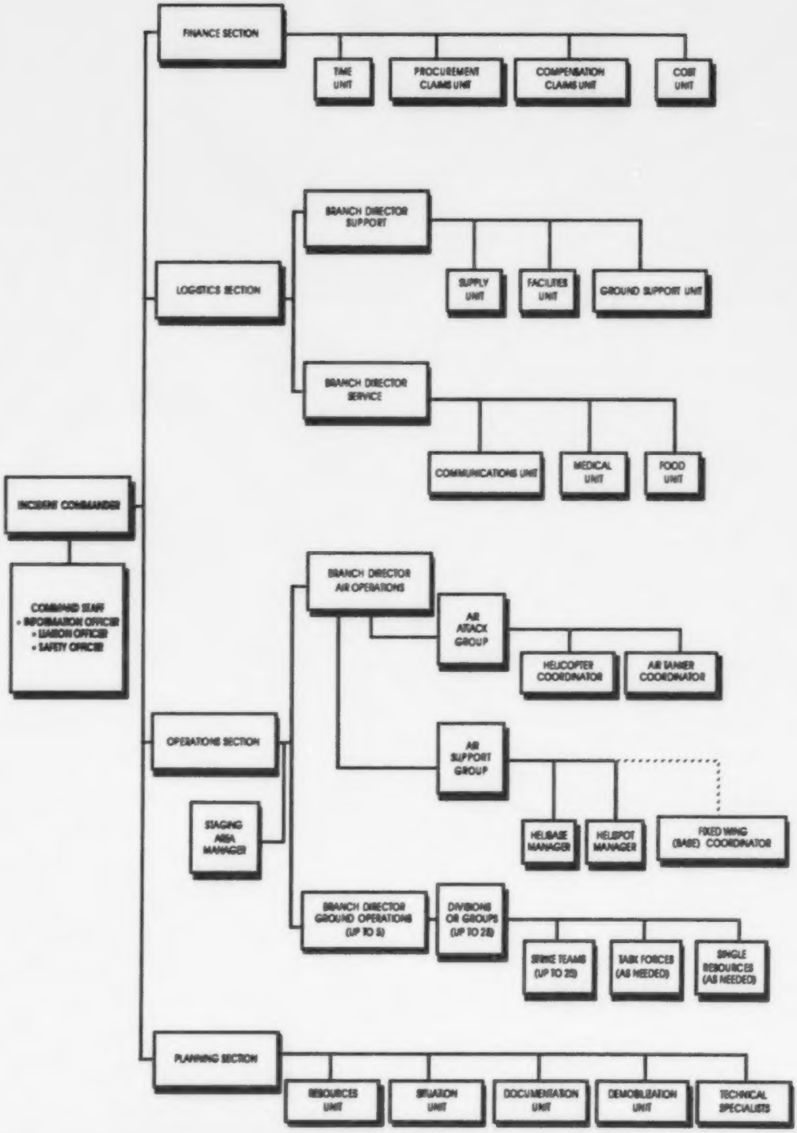
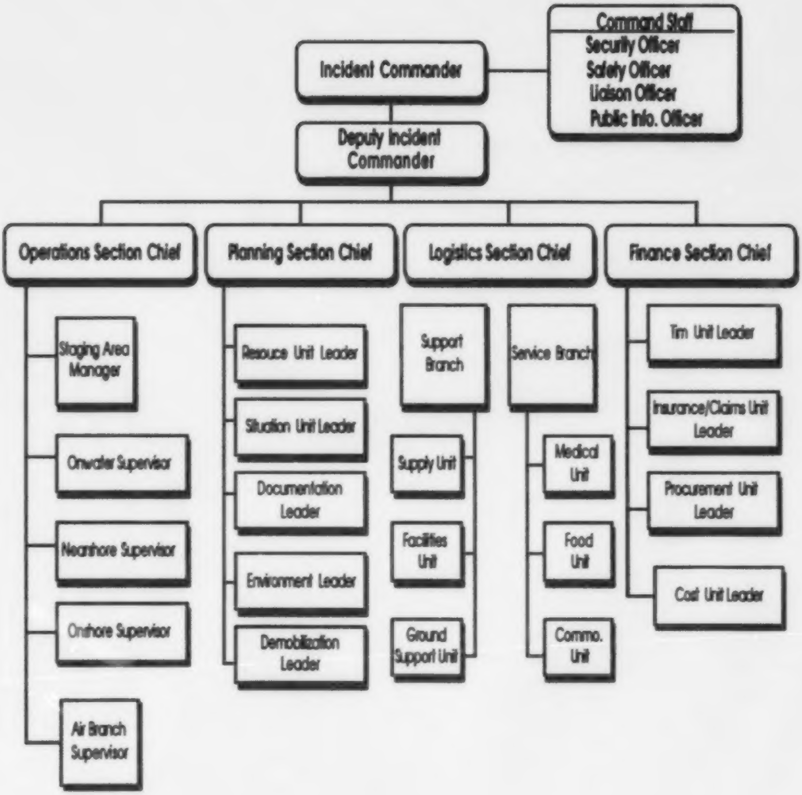

FINANCE SECTION
TIME UNIT
PROCUREMENT CLAIMS UNIT
COMPENSATION CLAIMS UNIT
COST UNIT
BRANCH DIRECTOR SUPPORT
LOGISTICS SECTION
SUPPLY UNIT
FACILITIES UNIT
GROUND SUPPORT UNIT
BRANCH DIRECTOR SERVICE
COMMUNICATIONS UNIT
MEDICAL UNIT
FOOD UNIT
INCIDENT COMMANDER
COMMAND STAFF
• INFORMATION OFFICER
• LIAISON OFFICER
• SAFETY OFFICER
BRANCH DIRECTOR AIR OPERATIONS
AIR ATTACK GROUP
HELICOPTER COORDINATOR
AIR TANKER COORDINATOR
OPERATIONS SECTION
AIR SUPPORT GROUP
STAGING AREA MANAGER
HELIBASE MANAGER
HELISPOT MANAGER
FIXED WING (BASE) COORDINATOR
BRANCH DIRECTOR GROUND OPERATIONS (UP TO 5)
DIVISIONS OR GROUPS (UP TO 25)
STRIKE TEAMS (UP TO 25)
TASK FORCES (AS NEEDED)
SINGLE RESOURCES (AS NEEDED)
PLANNING SECTION
RESOURCES UNIT
SITUATION UNIT
DOCUMENTATION UNIT
DEMOBILIZATION UNIT
TECHNICAL SPECIALISTS

FIGURE 4

ALYESKA ICS STRUCTURE FOR PRICE WILLIAM SOUND


Incident Commander
Command Staff
Security Officer
Safety Officer
Liaison Officer
Public Info. Officer
Deputy Incident Commander
Operations Section Chief
Planning Section Chief
Logistics Section Chief
Finance Section Chief
Staging Area Manager
Onwater Supervisor
Nearshore Supervisor
Onshore Supervisor
Air Branch Supervisor
Resouce Unit Leader
Situation Unit Leader
Documentation Leader
Environment Leader
Demobilization Leader
Support Branch
Supply Unit
Facilities Unit
Ground Support Unit
Service Branch
Medical Unit
Food Unit
Commo. Unit
Tim Unit Leader
Insurance/Claims Unit Leader
Procurement Unit Leader
Cost Unit Leader

By leaving the Operations Section undefined it can be structured according to the nature of the event: into Divisions if organized geographically and/or by Groups if organized functionally. This is in keeping with the organizational structure developed by NIIMS. Alyeska has been able to define their Operations Section in Prince William Sound in more detail due to the fact that they are responsible for responding to basically only one type of incident, a tanker spill within the Sound.

Two important modifications were made from the NIIMS organizational structure. Firstly, Air Operations was removed from the Operations Section and placed in the Logistics Section. This was done in recognition of the fundamental difference in the role of aircraft in an oil spill and a wildland fire. In a fire situation, aircraft are used extensively in attacking the fire through the application of retardant sprays as well as water bucketing. In a spill situation, with the exception of aerial application of dispersants (not considered to be a primary response option on the North Slope) or heli-torching there are no other instances where aircraft would be involved in attacking the spill. Their role is primarily oriented towards logistics. If the dedicated use of an aircraft is required for some aspect of operations (e.g. Helitorch) it can be temporarily assigned to Operations. Once that mission is accomplished the aircraft goes back to the control of Logistics.

The second modification was the addition of an Environment Unit in the Planning Section. The importance in having environmental input into the decision making process for spill response is generally accepted. While working to develop a common ICS structure for the North Slope the role of the environment component generated significant discussion. There were two schools of thought on this issue. One school believed that environmental input is of sufficient importance to require a separate section within the ICS organizational structure reporting directly to the Incident Commander. It was felt that this was the only way environmental issues would receive the recognition and consideration they deserved. The second school of thought recognized the importance of environmental input into the response effort. However, it was felt that by elevating environment to a Section level it would compromise 2 of the 8 components upon which ICS was structured: common terminology and modular organization. This school recommended leaving environment as a unit within the ICS structure. By ensuring that the person filling the Planning Section Chief position had a strong environmental background or appointing a Deputy Planning Section Chief with an environmental background, the potential problem of environmental issues not being elevated to a high enough level could be resolved. For the North Slope it was decided to leave environment as a Unit within the organization. However, this needs to be caveated by the point that where a Deputy is used, the two must coordinate very closely to ensure conflicting direction is not given.

A third issue which generated significant discussion when working on the organizational structure was whether a separate section was required for source control. The thought here was that for a blowout, due to the large quantity of resources required to mount a response (i.e.: drilling of a relief well) and specialized response, it would be better to have a separate section reporting to the Incident Commander. The Source Control Section would deal with the blowout and the Operations Section would deal with the oil spill. As with the environmental question it was determined that by placing the correct person in the Operations Section Chief position, both the spill response and the source control problem could be handled within the Operations Section. If required, a Deputy Operations Section Chief could be appointed to handle a particular aspect of the response.

As with all aspects of the current North Slope spill response planning, the ICS structure was developed and approved as a field line management responsibility with active grass roots participation. The whole process of coming to agreement on an ICS structure for North Slope spill response took approximately 6 months. The concept was first introduced to Field Managers in early October of 1990. By the end of March 1991, all Field Managers had agreed to the organizational structure recommended for the North Slope. The significance of 6 operating units coming to consensus on the adoption of a common response system should not be underestimated. It is an indication of the seriousness with which spill response is viewed on the North Slope and the commitment that the Operators have to ensuring the best possible response capability.

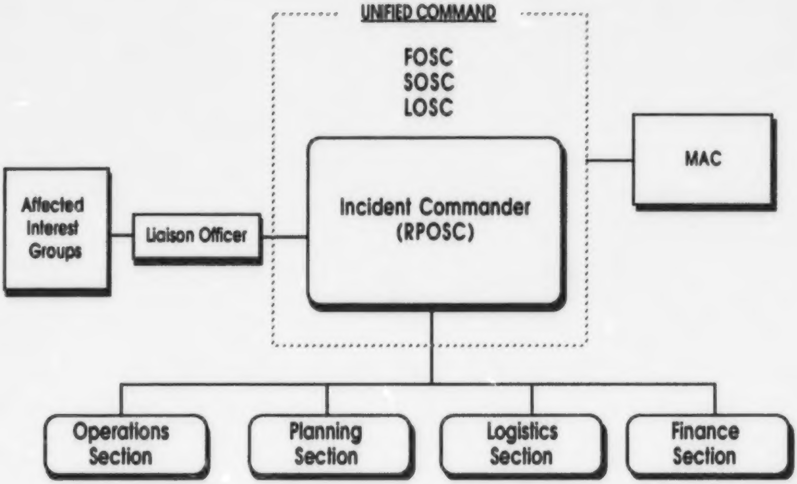
Unified Command

In spill incidents that involve multiple jurisdictions it is necessary to ensure that all agencies with regulatory responsibility contribute to the process of determining overall objectives and response strategies. A well defined joint decision making process is required that does not compromise any agency's authority. This is done through representation in a Unified Command.

The Unified Command structure developed for the North Slope is shown in *Figure 5*. Unified Command may be made up of the Federal On Scene Coordinator (FOSC), the State On Scene Coordinator (SOSC), the Local On Scene Coordinator (LOSC) and the Responsible Party On Scene Coordinator (RPOSC) Within the Unified Command structure there is only one Incident Commander (IC). This individual represents the organization in charge of responding to the spill. Decisions on objectives and response strategies are made jointly by the Unified Command. It is the responsibility of the IC to implement the objectives and response strategies.

Figure 5

NORTH SLOPE UNIFIED COMMAND STRUCTURE


UNIFIED COMMAND
FOSC
SOSC
LOSC
Incident Commander
(RPOSC)
MAC
Affected Interest Groups
Liaison Officer
Operations Section
Planning Section
Logistics Section
Finance Section

Individual Local, State and Federal agencies with jurisdictional responsibilities related to the spill have representation on a Multi-Agency Coordination Group (MAC). Their concerns and recommendations are funnelled to their respective On-Scene Coordinator who incorporates their input into the decision making process.

Affected interest groups and advisory bodies have input into the decision making process through the Liaison Officer of the Command Staff. The Liaison Officer is responsible for addressing these concerns and/or ensuring they are brought to the attention of the IC where appropriate.

The State of Alaska is still in the process of developing its master contingency plan for State and Regional response to spills. The State has adopted the ICS for its response to spills, but it is still in the process of determining how the State's ICS will be structured, particularly at the Unified Command level. A State Command Issues Working Group has been formed to assist the State in this area. There is representation from the oil industry on this working group.

Training

In order for ICS to be fully embraced on the North Slope it is crucial that an effective training program be developed and implemented. The training must be standardized with clear performance standards that are achievable and measurable.

On the North Slope the personnel that would initially respond in a spill and staff the ICS structure are taken from the existing work force. Involvement in the IRTs or Auxiliary Contractor Response Teams (ACRTs) is on a voluntary basis. The IRTs generally meet for two hours every week to receive training. They are also released from operational duties to take part in additional specific training courses and exercises as they arise.

A multi-phased program to provide ICS training has been developed. Firstly, as discussed earlier, all personnel responding to hazardous waste operations (Hazwoper) must be properly trained under both Federal and State OSHA requirements. Within this training there is a requirement to address the ICS system. As part of the Hazwoper training or as a supplement to it, a 2 hour ICS orientation providing a broad overview of the system and how individual responders would be involved was developed as a mandatory course for all IRTs, ACRTs, VRTs and ACS personnel. In total, factoring two shifts, this involves the training of initially approximately 700 people.

Anyone filling supervisory positions within the ICS organizational structure shown in *Figure 2* are strongly encouraged to have an 8 hour introductory ICS course. This course provides an understanding of how the 5 components of ICS work together to meet a common objective. In addition the interaction between the 5 functional areas is discussed in detail.

There are 4 advanced ICS training courses still in the developmental stage. These are specific to the basic organizational functions of ICS: command, logistics, operations and planning. Personnel filling a staff position in one of the Sections is provided detailed training in the functioning of their Section as well as their specific job duties. Personnel in the Finance Section are encouraged to attend one of the advanced courses. It is anticipated that the Finance section will be somewhat specific to the needs of the Spiller (i.e.: follow that company's financial procedure) therefore a common finance course is not considered necessary.

To ensure performance standards are met, all ICS courses have a test associated with them. Certificates are issued to the successful participants and their participation is recorded in a training data base. This serves several purposes. Firstly, it provides a record of all personnel who have ICS training. In a situation where a company calls for specific supplemental support under mutual aid, a list of several possible candidates can be readily identified. Secondly, it provides a system for demonstrating regulatory compliance with OSHA training requirements

Future Challenges

While the Alaska North Slope Producers have recognized the need for the implementation of an ICS system on the North Slope for oil spill response, there are several issues associated with this system that may ultimately impact on it. Firstly, the ICS concept is an all risk system. It can be applied to any type of emergency response. Its ultimate fate will depend on how well it is accepted as an organizational structure for other types of emergencies. The majority of the fire departments on the North Slope are organized along an ICS structure and have been for several years. With oil spill response now embracing an ICS structure it is anticipated that other emergency responses will eventually be organized along similar lines.

A significant challenge is how best to staff out an ICS structure in a large dynamic incident, particularly for supervisory positions. There are a number of potential solutions for this problem. Staffing can be done from within the company's North Slope operational staff; assistance can be requested from other parts of the company; consultants, ACS personnel or personnel from other companies are other options. This is a decision that must be made by each Operator, however, it is recommended that the best qualified and available person be assigned to the ICS positions regardless of his employment affiliation.

Conclusions

It is to the credit of the North Slope Operators that they have been able to transcend normal competitive boundaries to implement a common spill response organization that benefits all. The most significant achievement has not been the development of the organizational structure, but more the recognition that there had to be one structure. While the structure has not yet been tested in a drill or actual spill, a Level 2 mutual aid exercise is planned for August of 1991. This will be a major test of the ICS structure. It is anticipated that that there will be modifications to the system based on this experience. As more experience is gained the system will continue to be evaluated and will be modified if appropriate. The challenge will be to ensure that the final structure stays within the ICS mold, allowing it to continue as an all risk system and that any changes made are done through consensus of the North Slope Operators to maintain the benefits of a common and consistently understood game plan.

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SPILLS: THE LEGAL CONTEXT

by

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SPILLS: THE LEGAL CONTEXT

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ARCTIC AND MARINE OILSPILL PROGRAM
June 1, 1991

SPILLS: THE LEGAL CONTEXT

by Donna S.K. Shier and Barry N. Spiegel

I. INTRODUCTION

Manufacturers, handlers and transporters of waste or of toxic or regulated chemicals are subject to a number of environmental statutes. In Canada, statutes at the municipal, provincial and federal levels all impose legal obligations. These obligations include the duty to report spills, prevent further damage, clean-up spills, restore the environment and pay compensation to those who have suffered damage as a result of the spill.

In certain circumstances, companies and their directors, officers and employees may be charged with environmental offences. They may also be ordered to undertake clean-up and prevention programs, or to pay the costs of government action.

Statutory obligations and consequent costs can apply to everyone in the chain of ownership, management or control of a spilled chemical, even if the company or individual was not at fault, or involved with the spill.

This paper begins with a brief description of some of the most significant provincial and federal statutes affecting industrial manufacturers, producers, and handlers and transporters of oil and chemicals. Because the regulatory structure in Canada is unconsolidated, a comprehensive description or comparison of all statues dealing with spills goes beyond the scope of this paper. Therefore, several statutes were selected for more specific examination.

Legal obligations to report spills, take preventative and remedial action and pay compensation are compared in the Canadian Environmental Protection Act (CEPA), the Ontario Environmental Protection Act (EPA) and the British Columbia Waste Management Act (WMA).

Each of these statutes vests wide powers of investigation and enforcement in officers of the corresponding ministries. Premises may be searched, samples and statements taken, and charges laid.

The latter part of this paper discusses the legal position of directors, officers and employees in companies under investigation. Individuals may be under a statutory obligation to cooperate with investigating officers. However, where an individual may be charged with an offence the compulsion to cooperate in the investigation must be balanced against the right to counsel, the right to remain silent and the right against self-incrimination codified in the Charter of Rights and Freedoms.

II. STATUTORY FRAMEWORK

The handling and disposal of materials having potential environmental impacts are regulated in Canada by a profusion of statutes and by-laws at the federal, provincial and municipal levels.

Statutory reporting obligations can be very confusing; they can vary according to the municipality and province in which a spill takes place, according to the material which is spilled, and according to the classification of the event. In Ontario, for example, there are different reporting requirements for "discharge", "spill", upset or shut-down events. A spill which is reportable in British Columbia may not be reportable in Ontario.[1]

The agents or agencies to whom reports must be made also vary according to location and nature of the spill. The Ontario EPA does not specify minimum quantities of materials spilled for the purposes of reporting or enforcement, other than to state that a "spill" is an event which is, among other things, "abnormal in quality or quantity in light of all of the circumstances of the discharge".

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[1] For example, a spill in Ontario which does not escape from the building in which it is spilled need not be reported; but an air emission within a second building or structure as a result of the spill in the first building must be reported.(EPA section 1a). In British Columbia, reporting requirements under the Spills Reporting Regulation of the WMA have been interpreted to exempt reporting of spills which discharge into containment buildings.

A. PROVINCIAL SPILLS REPORTING CENTRES

In both Ontario and British Columbia efforts have been made to coordinate the reporting of spills between federal and provincial governments and to ensure appropriate reporting and response by agencies at every level of authority.

Ontario has established the Spills Action Centre; the B.C. equivalent is the Provincial Emergency Program. These offices are often the coordinators of reporting and response for spills, whether "routine" or emergency.

Spills may be reported directly to these offices which are staffed around the clock. Staff members will advise on the nature of the reporting obligations and may undertake to notify the appropriate federal, provincial and municipal agencies as required. They will also contact other potentially affected parties and agencies including the Coast Guard and U.S. authorities. The Ontario Spills Action Centre has 24 hour access to the Minister of the Environment.

The spill reporting centres also advise on emergency response and clean-up resources and contact appropriate emergency response organizations at various levels of government, from police, fire, ambulance and public works to provincial and federal environment officials.

CEPA, S. 36(4), provides that if a province has provisions in force for dealing with a release of toxic substances the Governor General can make regulations allowing the mandatory report to be made to the "person designated by the provincial provisions." Regulations under this section are not yet in force.

The staff of both the Ontario and B.C. offices will report spills to federal officials in the appropriate cases.

B. STATUTES: EXAMPLES - CANADA, B.C., ONTARIO

Table 1 sets out some examples of statutes that regulate the handling and transportation of regulated substances or materials that may have adverse effects on the environment. This list is not comprehensive, but allows some perspective on the various interests and jurisdictions concerned with spills and discharges.

C. COMPARISON OF CEPA, EPA AND WMA

The most comprehensive statutes regulating spills (other than those in the Arctic or in Maritime waters) are, in Ontario, the Environmental Protection Act, and, in British Columbia, the Waste Management Act.

The Canadian Environmental Protection Act is relatively new but has sharp teeth when it comes to spills of scheduled chemicals. Additional regulations are being formulated that will give CEPA greater influence in the transportation and use of a number of industrial materials. To date, however, these regulations are not yet in force.

TABLE 1: EXAMPLES OF ENVIRONMENTAL STATUTES REGULATING HANDLING, USE AND TRANSPORTATION OF POTENTIALLY CONTAMINATING OR POLLUTING MATERIALS

CANADA	**ONTARIO**	**BRITISH COLUMBIA**
Canadian Environmental Protection Act	Environmental Protection Act	Waste Management Act
Canada Shipping Act	Gasoline Handling Act	Pipeline Act
Fisheries Act	Ontario Water Resources Act	Environmental Management Act
Transportation Of Dangerous Goods Act	Dangerous Goods Transportation Act	Transport of Dangerous Goods Act
Arctic Water Pollution Control Act	Pesticides Control Act	

The Ontario Environmental Protection Act regulates waste management, discharges and spills into the environment. Specific regulations govern hazardous wastes (Regulation 309), air emissions (Regulation 308), PCB's (Regulation 11/82). The Act imposes duties on those who own or control regulated contaminants or those contaminants which may cause adverse effects. The Act also establishes responsibility for clean-up of contaminated properties by current or prior owners of the land or business.

The Waste Management Act of British Columbia, like the EPA, regulates waste management and substances which may damage the environment. While it is generally not as comprehensive in application nor as strict in its requirements as the Ontario Act, it establishes by regulation in Provincial Emergency Program for spill reporting and spill management. Amendments are now being formulated to improve control over contaminated land.

These three statutes set "the legal context" to which handlers, users or transporters of oil and chemicals are subject.

D. CONTAMINANTS AND POLLUTANTS

Regulations under CEPA and B.C.'s Waste Management Act establish minimum amounts of specific classes of chemicals which must be regarded as spills. A discharge in excess of the minimum will trigger reporting and clean up obligations. Ontario's EPA puts the onus on the individual user to determine whether a substance may have an adverse effect, and therefore must be reported and dealt with accordingly to the statutory requirements.

Regulations under CEPA have defined several classes of chemicals over which it asserts jurisdiction to order reporting, clean-up and restoration and to impose sanctions. Currently regulations are in place designating certain substances "toxic". A substance is "toxic" if it enters the environment in quantity, concentration or under conditions which may have an immediate or long term harmful effect on the environment or constitute a danger to human life, health or the environment on which human life depends.

The federal Minister of the Environment is permitted to make an interim order designating a substance toxic if the Minister believes it is toxic or not adequately regulated and that immediate action is required to deal with a significant danger to the environment or human life or health.

The EPA (Ontario) asserts jurisdiction over "discharges" of "contaminants" and "spills" of "pollutants". The definition of "contaminant" is comprehensive; it includes emissions, leaks and deposits of solids, liquids, gases, noise, heat and radiation that may cause an adverse effect. Any discharge of a contaminant which exceeds regulated standards must be reported.

Part IX of the Act, known as the Spills Bill, establishes more onerous duties where there is a "spill" of a "pollutant". A pollutant is defined as a contaminant (a regulated substance or one which is likely to cause an adverse effect) which does not include heat, sound or radiation. A "spill" is a separately defined event, and is discussed below.

WMA (B.C.) defines several categories of material which give rise to regulation. WMA, like the Ontario EPA, has special spills provisions. Section 10 of the Act describes a "polluting substance" as any substance whether gaseous, liquid or solid that could, in the opinion of the Minister, substantially impair the usefulness of land, water or air if it were to escape into the air or were spilled on or were to escape onto any land or into any body of water.

The "Spill Reporting Regulation", B.C. Reg. 263/90, enumerates in Schedule I classes of polluting substances. The regulation establishes minimum quantities which trigger the reporting requirement. Nineteen classes of substances are included which refer either to federal regulations or the B.C. Special Waste Regulation. For example, discharges in excess of 50 kg of waste asbestos, 100 litres of flammable liquids or 5 kg of corrosive or poisonous gasses all require reporting. According to the regulation spills of the latter two substances may only require reporting if they result from equipment failure, error or deliberate action or inaction.

The Class 20 in the Schedule of the Spills Reporting Regulation requires reporting of any spill in excess of 200 kg of "a substance not covered by items 1-19 that can cause pollution."

III. WHAT IS A SPILL?

A. CEPA

Section 36 of CEPA creates reporting and emergency notification duties where a release occurs or there is a reasonable likelihood of a release into the environment of a toxic substance in contravention of the regulations governing the use of that substance. "Release" includes "discharge, spray, eject, inoculate, abandon, deposit, spill, leak, seep, pour, emit, empty, throw, dump, place and exhaust". Note that Section 57(1) imposes corresponding obligations in respect of substances designated by regulation under Section 54, relating to federal works, undertakings or lands. For example, 50R/90-5 regulates mobile PCP treatment and destruction on federal lands or under contract with federal institutions.

Currently there are 9 classes of chemicals designated as toxic on Schedule I. Generally, regulations have been enacted to control or prohibit their use and release.

B. EPA

The EPA requires reporting of all discharges of contaminants that exceed regulated standards or which may cause an adverse effect. Part IX, The Spills Bill, was enacted in 1985 contains special and more onerous requirements for the owners and controllers of pollutants which are spilled.

Section 79(1)(j) defines a "spill" as a discharge of a pollutant:

- i) that enters the natural environment;
- ii) from or out of a vehicle, structure or other container; and
- iii) that is abnormal in quality or quantity in the circumstances.

A spill causes or is likely to cause an adverse effect on the natural environment or on the health, safety, comfort or business of people, a duty is imposed on the owner, controller and anyone who causes or permits the spill must comply with all of the requirements of Part IX.

C. WMA

The spill prevention and reporting section (s.10) of the Act imposes duties when a polluting substance "escapes or is spilled or waste is introduced into the environment other than as allowed or authorized...". The "Spill Reporting Regulation" (B.C. Reg. 263/90) defines spill as a release or discharge except as authorized and allowed under specified provisions of the Act or by permit, approval or order, of an amount equal to or greater than the amount limited in the Schedule. The schedule sets out classes of substances which are regulated, minium amounts, and, as noted above, in certain cases, reasons for release or spill.

IV. STATUTORY REPORTING OBLIGATIONS

Table 2 companies CEPA, EPA and the WMA describing who must report, when, the nature of the report required and to whom the report(s) must be made.

V. LIABILITY OF OFFICERS AND DIRECTORS

Table 3 compares the sections imposing individual personal liability under the provisions of CEPA, EPA and the WMA.

VI. STATUTORY DUTIES AND COMPLIANCE ORDERS: ONTARIO

The legal context in Ontario is a good model for understanding the duties and dilemmas facing those who spill and those who must deal with spills. The Ontario Ministry of the Environment (MOE) currently has an aggressive enforcement policy resulting in prosecutions of companies and individuals who own or control contaminants entering the natural environment.

A. THE REPORTING DILEMMA

While some specific pollution regulations establish minimum standards for the purpose of mandatory reporting[2], the provisions of the Ontario Spills Bill do not. An owner or controller must decide in each situation if an event is a spill and must be reported. The penalties for failing to report can be up to $50,000.00 per day on a second or subsequent conviction.

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[2] In contrast, Ontario Regulation 308 (EPA), which regulates air pollution, establishes minimum standards for visible emissions. The B.C. Spills Regulation, supra, establishes minimum quantities; spills of quantities less than those in the Schedule need not be reported.

TABLE 2: STATUTORY REPORTING OBLIGATIONS

STATUTE	WHO MUST REPORT	WHEN	Nature of Report	REPORT TO WHOM
CEPA	any person who: a) owns or has charge of a substance immediately before its release or likely release; or b) causes or contributes to, or cause increases the likelihood of, the initial release	as soon as possible in the circumstances	report the matter	-to an inspector or other person designated by regulation; and -make a reasonable effort to notify any member of the public who may be adversely affected
EPA	owner and controller and anyone who causes or permits spill	immediately he knows the pollutant is spilled and is causing or is likely to cause an adverse effect	notify of spill, circumstances, actions person has taken or intends to take, and supply additional information re pollutant, source and spill as required by Director	1.Ministry of Environment; 2.local municipality; 3.regional municipality; 4.owner of pollutant; and 5.controller of pollutant
WMA	the person who had possession, charge or control of the substance or waste immediately before the escape, spill or introduction	immediately after he learns of the escape, spill or introduction	a)reporting person's name and phone; b)name and phone of person who caused spill; c)location and time of spill; d)type and quantity of substance spilled; e)cause and effect of spill; f)details of action taken or proposed to stop, contain and minimize effects; g)description of location and surrounding area; h)details of further action; i)names of agencies on the scene; and j)names of other persons or agencies notified.	report to PEP-Provincial Emergency Program, (phone numbers are set out in the regulation), or where not practical to report to PEP within a reasonable time, to local police or nearest R.C.M.P.

TABLE 3: LIABILITY OF OFFICERS AND DIRECTORS

CEPA: Section 122	**EPA**: section 147a	**WMA**: section 34(10)
122 Where a corporation commits an offence under this Act, any officer, director or agent of the corporation who directed, authorized, assented to , acquiesced in or participated in the commission of the offence is a party to and guilty of the offence, and is liable to the punishment provided for the offence, whether or not the corporation has been prosecuted or convicted.	147a(1) Every director or officer of a corporation that engages in an activity that may result in the deposit, addition, emission or discharge of a contaminant into the natural environment contrary to this Act or the regulations has a duty to take all reasonable care to prevent the corporation from causing or permitting such unlawful deposit, addition, emission or discharge. (2) Every person who has a duty under subsection (1) and who fails to carry out that duty is guilty of an offence. (3) A director or officer of a corporation is liable to conviction under this section whether or not the corporation has been prosecuted or convicted.	34(10) Where a corporation commits an offence under this Act, an employee, officer, director or agent of the corporation who authorized, permitted or acquiesced in the offence commits the offence notwithstanding that the corporation is convicted.
FINES AND PENALTIES: Sections 11-133	FINES AND PENALTIES: Section 146-147	FINES AND PENALTIES: Section 34
Fines Maximum fines for individuals for failure to give information, obstruction and failure to report are $200,000.00. Maximum fines for pollution offences may be as high as $1,000,000.00 and may be indictable offences. Where the offender has acquired monetary benefits the court may impose a fine in excess of the maximum fines otherwise allowed. Imprisonment Information, obstruction, reporting and pollution offences on summary conviction hold a maximum six month jail term. Pollution offences on indictment hold a five year maximum sentence.	Fines Fines for individuals range from (maximums): i) on first conviction, $5,000.00 for each day or part of a day the offence is committed or continues ($50,000.00 where the offence relates to hauled liquid industrial waste or hazardous waste); and ii) on second and subsequent conviction, $10,000.00 per day or part of a day ($100,000.00) for hauled liquid industrial waste or hazardous waste). Imprisonment Maximum one year.	Fines Maximum fines for information and pollution offences range from $200,000.00 to $1,000,000.00. Imprisonment Maximum six months.

Many Ontario companies have established Spills Action Programs for complying with Part IX of the EPA. Employees are taught "if you have to wipe it up then its a spill", and instructed to report every incident to the person in charge of spills action, who in turn must decide whether or not to report it.

Ontario's Minister of the Environment has stated that:

> Strict reporting requirements and increased enforcement have convinced industry that it is in its best interests to report all spills.[3]

One result has been the increase in reporting of spills since 1986 by about 20% each year. 5,345 spills were reported in Ontario in 1989, according to a report release in March of 1991 by Ontario's Spills Action Centre. Of these, approximately one-third were less than 10 litres. Approximately one-half of all reported spills involved oil or fuel.[4]

Emphasis by the MOE on enforcement rather than abatement may foster reluctance to report. In many cases without a report the Ministry would have no knowledge of a given incident, that is, nothing on which to base a charge for a pollution offence. Since pollution offences carry incrementally greater fines (for subsequent convictions) and require costly legal defence, some say that corporate risk management mitigates in favour of interpreting only larger more visible events as reportable spills.

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[3] Ministry of the Environment News Release, February 22, 1991.

[4] Ministry of the Environment News Release, February 22, 1991. Distribution of spills among industrial sectors reporting was: transportation-13.4%, petroleum-13.3%, chemical-10.9%, metallurgical-9.4%, and electric utilities-10.6%. Sewage treatment plants, other industrial, agricultural and residential sources accounted for less than 5% each.

A recent Ontario General Division decision in the case of R. v. Weil's Food Processing Ltd. and Henry Weil (unreported decision of Browne J. released December 4, 1990) has recognized the dilemma facing those who are involved in what may later be determined to be a "spill". The judgement considered whether the mandatory reporting requirements of EPA s. 14(1) and s. 16(2) of the Ontario Water Resources Act violate the principle of the right to silence provided by the Canadian Charter of Rights and Freedoms. Mr. Justice Brown stated:

> It is a desirable goal that notice be required and that failure to give notice be an absolute liability offence. I find it surprising that the legislation requiring the giving of notice does not provide further that the compliance would not be admissible against a party giving the notice. As the legislation now stands the giving of notice would not be a neutral fact. The giving of the notice and the particulars given would almost certainly be elements in establishing other offences. What does the citizen do? If they fail to give notice, that is an absolute liability offence. If notice is given, it may be used against the interest of the giver. The goal of seeking the giving of notice is frustrated by the built-in conflict....I conclude there is a clear infringement of s. 7 of the Charter subject to any relief that may be available pursuant to subsection 1.

In late June of 1991 the court will hear further argument on whether section 1 of the Charter applies to the reporting requirements. Section 1 guarantees Charter rights subject to "such reasonable limits prescribed by law as can be demonstrably justified in a free and democratic society".

If the court concludes that the legislation offends the Charter this case will certainly be appealed; it may well find its way to the Supreme Court of Canada.

B. CLEAN-UP, PREVENT FURTHER DAMAGE, RESTORE

In Ontario, both the owner and the controller of a spilled pollutant that causes or is likely to cause an adverse effect, whether or not at fault for the spill, has a statutory duty to forthwith do "everything practicable to prevent, eliminate and ameliorate the adverse effects and to restore the natural environment".

The duty arises immediately when the owner or controller knows or ought to know that the pollutant is spilled and is causing or is likely to cause an adverse effect.

The British Columbia Spill Reporting Regulation is less onerous. It requires that:

> Where a spill occurs, the person who immediately before the spill had possession, charge or control of the spilled substance shall take all reasonable and practical action, having regard for the safety of the public and of himself or herself, to stop, contain and minimize the effects of the spill. (s.3)

C. PAY COMPENSATION

The Ontario EPA provides that any person, including the Governments of Ontario and of Canada have a right to compensation for:

i) loss or damage incurred as a direct result of a spill; and

ii) for all reasonable cost and expense incurred in complying with orders or directions of the Ministry to prevent, eliminate and ameliorate adverse effects or restore the natural environment.

This compensation is payable by an owner or person having control of a pollutant. Certain elements of the compensation can be avoided if the owner or controller can establish that:

- i) he took all reasonable steps to prevent the spill; or
- ii) the spill was caused by,
    - a. an act of war, terrorism or international hostility; or
    - b. a natural phenomenon of exceptional, inevitable and irresistible character; or
    - c. an act or omission by a third party _with intent to cause harm_.

Additional specific provisions provide municipalities and certain classes of persons rights to act to prevent, eliminate and ameliorate adverse effects and restore the environment, and to recover compensation for costs and expenses incurred in so doing from the owner or controller of the pollutant, whether or not he was negligent or at fault.

D. OTHER ORDERS

The statutory obligations discussed above are those clear obligations arising directly from the statute. Most environmental protection statutes also give discretion to appropriate authorities, including directors, ministers, inspectors and provincial officers to make special orders for the control, prevention, and clean-up of discharges.

The EPA provides that orders may be made, for example, for clean-up; if an owner or controller fails to comply with the order the government may do the work and collect the costs from owners or _former owners_ or anyone who has _or had_ management or control of a business or undertaking.

The EPA was recently amended to remove the right to an automatic stay of an order pending appeal. Therefore, a company is under an obligation to comply with an order even while the order is under appeal.

VII. THE INVESTIGATION DILEMMA - COOPERATE OR REMAIN SILENT

Every corporate director, officer or employee who may be charged with an environmental offence or otherwise exposed to liability resulting from a spill is faced with a dilemma. An individual has a duty to abate an environmental problem. However, when the information supplied may be used against the individual as evidence in an environmental prosecution, the individual also has the right to remain silent. The right to remain silent operates in situations where a person's disclosure of information might tend to incriminate that person.

These issues are now before the Ontario courts in R v. Weil as discussed above.

A. POWERS TO INVESTIGATE

Most environmental statutes provide provincial or federal officers with the power to investigate spills. In Ontario under the EPA, these powers include the right to enter land, premises and vehicles and make tests and inspections as well as examine books and records. Samples, copies and extracts may be taken or made or detained.

Provincial police may be called upon to assist and are under statutory obligation (EPA section 128) to render assistance.

Similar provisions are found in Part 4, section 21 of the WMA and CEPA Sections 76 and 100-105.

B. OBLIGATION TO COOPERATE (EPA)

Section 127(3) of the Environmental Protection Act of Ontario provides:

> s.127(3) Every person responsible for a source of contaminant shall furnish such information as a provincial officer requires for the purposes of this Act or the regulations.

Obstruction of a provincial officer, refusing to provide information or providing of false information may all give rise to charges under the Act.

See also WMA Sections 21 and 34, and CEPA Section 102.

C. RIGHT TO COUNSEL

Section 126(4) of the EPA provides that a person has a right to have counsel present when answering inquiries made by a provincial officer.

The Canadian Charter of Rights and Freedoms provides that everyone has the right on arrest or detention to retain and instruct counsel without delay and to be informed of that right[5]

The right to counsel at common law continues to be valid and is not replaced nor derogated from by the Charter.

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[5] Canadian Charter of Rights and Freedoms, section 10(b).

D. WHEN IS AN INSPECTION AN INVESTIGATION?

In Ontario the Ministry has established two kinds of provincial officers who investigate spills. Abatement officers conduct routine and scheduled inspections to ensure compliance with certificates of approval, control orders and regulatory standards. They also respond to emergencies and citizen complaints. If abatement officers become aware of possible offences, they may become the initial investigating officers.

The Ministry has also established an autonomous branch (the Investigations and Enforcement Branch) whose officers are primarily involved in investigation and prosecution of offences.

Both categories of provincial officers, in the course of their duties may gather information that will be used in the course of prosecution at a later date.

For example, careless handling of chemicals which spill into sewers, watercourses or groundwater is a common starting point for investigations which result in the laying of charges. Often these investigations result in charges not only for the spill but for breaches of other provisions, including reporting or paperwork requirements. Management and employees may have overlooked or been unaware of the requirement to register the handling of hazardous waste. The report of a small spill may trigger an investigation which discloses that drums of hazardous materials for a manufacturing process have been stored or buried on the manufacturer's property without approval or that certain equipment doesn't have proper authorization.

If the unfortunate company has not recently audited its operations, an investigation may reveal old manufacturing processes that no longer comply with existing regulations, contaminant leaks, leaking underground storage tanks, or unlicensed discharges to sewers.

Ignorance is no defence. The standard of conduct required of a company and its executives is "due diligence".

The consequences of a minor spill and investigation can be far greater than first imagined.

E. IS A ROUTINE INSPECTION SERIOUS?

Routine inspections conducted by abatement officers can be the source of information later used as the basis for prosecution. Every inspection should be treated seriously and a protocol should be established beforehand.

F. HOW SHOULD AN INDIVIDUAL RESPOND

1. What Should I Do To Prepare For An Inspection?

Staff should be trained and there should be a designated contact person to liaise with ministry officials and attend all ministry visits. A log book should be kept with a record of every visit, the participants, what was inspected, the questions asked and the answers given.

Duplicate samples should be kept and independently analyzed whenever the inspector takes samples or runs tests. The designated staff member should accompany the ministry representative at all times.

Staff should be aware of the obligation to cooperate with the reasonable requests of the officer. He or she may require equipment to be demonstrated, tests to be run, or documents, including log books and computerized information to be produced. Every person is under an obligation to furnish information to the officer. It is an offence to furnish false information or to obstruct an investigation in any way.

Inspectors may take notes on the scene, or may appear casual, but take notes after the inspection, which may later be used at trial to refresh the memory. Casual conversation with a provincial or federal officer when there is potential for an investigation can be dangerous. All employees and management should be polite and courteous, but not volunteer information.

2. What Should I Do If I Am Investigated?

Ministry representatives may phone first, or just show up. It is generally advisable to make clear that you are willing to cooperate, however you would prefer to answer questions with your lawyer present. In Ontario the Ministry will usually defer to your wishes, unless there are urgent circumstances such as an immediate threat to the environment.

If the officer tries to conduct a telephone interview, you should get his or her name, phone number, badge number, and ask what he is seeking and what charges, if any, are being contemplated. You should only answer questions in the presence of legal counsel; therefore, arrange a mutually convenient time for a personal interview.

3. What If I Am Asked Incriminating Questions?

Provincial officers have different approaches to investigations. The casual conversation and the black notebook are sometimes replaced by a demand for a statement.

If the laying of charges against you personally is contemplated the provincial officer should read several cautions to you which will inform you of the charges which are contemplated, and ensure that you are giving the statement voluntarily.

A self-incriminating statement must be given voluntarily to be admitted as evidence in court.

Representatives of the Ontario Ministry have publicly stated that an individual may refuse to give a statement or may terminate an interview at any time. However, threats have been made on occasion to charge individuals for obstructing an investigation or failing to furnish information.

When informed that a statement is being taken, that charges may be laid, or when threatened with a charge for obstruction or failure to furnish information, you should immediately request an opportunity to consult with legal counsel, and should make every reasonable effort to contact counsel and get legal advice before giving any more answers.

To date no individual in Ontario has been charged with failing to furnish information or obstruction for refusing to answer questions or provide information pending consultation with a lawyer. The Ministry may well change its policy in the future. However, the Canadian Charter of Rights and Freedoms protects individuals from self-incrimination, and we expect that where there is a possibility that an individual will be charged, the right to remain silent will prevail.

4. What Is the Best Way to Cooperate While Avoiding Incriminating Answers?

Investigating officers often ask very general questions, such as: "So, what do you know about all of this?", or "What do you have to say?". Most individuals are inclined to be helpful, and this type of question is an invitation to give an unnecessarily long and perhaps damaging answer.

We recommend that general questions should not be answered with long, detailed and rambling answers. It is far better to suggest that you will answer specific questions.

It is important to understand the question, so be sure you know what you are being asked. If questions contain words with different definitions or connotations, be sure to get the provincial officer to define what he or she means, or to rephrase the question, before answering.

Do not give answers to questions that require you to:
-speculate or give opinions or theories;
-describe events that you were not present for and do not have direct knowledge of; or
-comment on motive or intention.

If a yes or no will suffice, do not expand. Only answer the question that is asked, not what you would have asked, or what the inspector should have asked.

5. Should I Sign a Statement?

Obtain from the provincial officer a copy of any statement and give it to your lawyer. In Ontario there is no obligation to give a signed statement. Therefore it is not advisable to sign any statement that may have been recorded by the officer.

6. When Should I Consult My Lawyer?

Right now. If your company is involved in any industrial or manufacturing process or otherwise regulated operation it is important to:

a) establish environmental management policies to ensure due diligence;

b) audit for compliance and risk of hazards;

c) train and instruct employees and consultants in pollution prevention procedures;

d) establish policies and strategies for dealing with routine inspections and special investigations, including the designation of contact persons, logbook recording of contacts and information, training and instruction in dealing with provincial officers, and protocol for contacting legal counsel.

VIII. CONCLUSION

We believe that environmental offences will be more aggressively pursued by the government and environmental interest groups in the future. The best defence to an environmental offence is to prevent it in the first place. If an unfortunate incident occurs, it is essential to ensure that systems are in place to mitigate the effects on the environment, the corporation and the public involved through sound and strategic planning and preparation.

Environmental auditing and the implantation of sound environmental due diligence policies at management through operation levels will have a positive effect on the corporate bottom line.

Prompt and informed response to environmental emergency events means minimized environmental effects, and reduces exposure to costly clean-up programs, compensation obligations and civil liability.

Due diligence in management and operations is a defence to most environmental charges.

Even where convicted of an offence, a business should be able to demonstrate that it made all reasonable efforts to prevent a spill, discharge or other offence and that it quickly and diligently

mitigated environmental damage and social and economic consequences. Responsible behaviour will minimize the size of fines imposed by the courts. A review of the maximum fines set out in Table 3 demonstrates the serious economic consequences of postponing environmental management measures until after an offence occurs.

Public concern about the state of the environment will continue to be manifested by the laying of more charges by the government and the imposition of stiffer sentences by the judiciary.

Diligent and attentive management of environmental consequences has become a significant legal, financial and social management imperative.

OVERVIEW OF THE U.S. OIL POLLUTION ACT OF 1990

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Introduction

After unanimous passage by both Houses of Congress, the Oil Pollution Act of 1990 (OPA) was signed into law by President Bush on August 18, 1990. Seven similar proposals had been defeated over the past 15 years. The March 1989 *Exxon Valdez* spill, however, as well as three other major discharges that occurred during a 24-hour period the following summer, solidified a broad-based support for the OPA.

The perception in Congress was that the current costs of spilling oil and paying for cleanup are not high enough to encourage industry to devote the necessary resources to preventing spills. Statistics on the frequency of major oil spills appear to support this view; there were 36 oil spills in U.S. waters exceeding 100,000 gallons in 1989 and 32 such spills in 1990. One purpose of the OPA, therefore, is to make spill prevention and response efforts financially expedient for industry. The other major goal was to ensure that the Federal response system is adequately prepared for potentially catastrophic oil spills that do occur.

The key elements of the OPA are a comprehensive Federal liability framework, increased Federal response authority and penalties, expanded spill preparedness measures, new spill prevention measures, and an interagency research and development program. Each of these elements is discussed, in turn, below.

Comprehensive Federal Liability Framework

The OPA adopts and extends the standard of liability promulgated under section 311 of the Clean Water Act, a standard that has been determined repeatedly to provide for strict, joint, and several liability. Under the OPA, the owner or operator of a vessel or facility (defined as the "responsible party") from which oil is discharged, or which poses the substantial threat of a discharge of oil, is liable for damages and any removal costs incurred in a manner consistent with the National Oil and Hazardous Substances Pollution Contingency Plan (NCP).[1] Six categories of damages are compensable under this section:

- Natural resource damages, including the reasonable costs of assessing these damages;
- Real or personal property damages;
- Loss of subsistence use of natural resources;
- Net loss of tax and other revenues;
- Loss of profits or earning capacity; and

Net cost of additional public services provided during or after removal actions.

Exceptions and Defenses to Liability

Exceptions to the liability provisions of the OPA are allowed for: (1) discharges of oil that are authorized by permit under Federal, State, or local law; (2) discharges emanating from a public vessel (except where the vessel is engaged in commerce); or (3) discharges from onshore facilities subject to the liability regime specified under the Trans-Alaska Pipeline Authorization Act. In addition, a responsible party will not be held liable to a claimant if the responsible party can show that the spill was caused by the claimant's gross negligence or willful misconduct.

Section 1003 of the OPA exonerates the responsible party from the liability provisions of the Act if the responsible party can prove by a preponderance of the evidence that the spill was caused by: (1) an act of God; (2) an act of war; (3) an act or omission by a third party; or (4) any combination of the three previous situations. To win a third party defense, the responsible party must prove that it took due care in handling the oil and took precautions against any foreseeable acts of the third party and any foreseeable consequences of those actions.

The defenses contained in section 1003 are not available to responsible parties that fail or refuse to report an incident of which they are aware, do not cooperate with response officials on removal actions, or do not comply with an order issued under section 311 of the Clean Water Act or the Intervention on the High Seas Act.

Limits on Liability and Financial Responsibilities of Responsible Parties

Liability limits under the OPA are significantly higher than those under the Clean Water Act. Liability for tank vessels larger than 3,000 gross tons is increased to $1,200 per gross ton or $10 million, whichever is greater. For tank vessels smaller than 3,000 gross tons, liability is capped at $1,200 per gross ton or $2 million, whichever is greater. Parties responsible for discharges from non-tank vessels are liable for up to the greater of $600 per gross ton or $500,000. Maximum liability for offshore facilities is the total of removal costs plus $75 million. Liability for onshore facilities and deepwater ports is $350 million. The OPA does not preempt State laws, which may impose additional liability, penalties, or cleanup requirements.

The OPA establishes certain conditions under which liability is unlimited: (1) discharges caused by gross negligence, willful misconduct, or violation of applicable Federal safety, construction, or operating regulations; (2) failure to report a spill; and (3) failure or refusal to cooperate in a removal action.

Responsible parties for vessels over 300 gross tons and vessels using the waters of the exclusive economic zone must establish and maintain evidence of financial responsibility up to the maximum liability to which the responsible party could be subject.[2] Any vessel subject to this requirement that cannot produce evidence of financial responsibility will not be allowed to operate in U.S. waters. The implications of this provision become significant in light of a State's prerogative to increase the maximum liability provisions. A State that opts for unlimited liability could render vessels uninsurable and thus unable to operate in its waters.

Recovery by Foreign Claimants

Section 1007 of the OPA states that foreign citizens are entitled to damage claims when there has been a discharge, or threat of a discharge, into the territorial sea, internal waters or adjacent shoreline of the claimant's country and one of the following is the source of the discharge or threat: (1) an Outer Continental Shelf or deepwater port facility; (2) a vessel within the navigable waters of the U.S.; (3) a vessel carrying cargo between two ports subject to the jurisdiction of the U.S.; or (4) a tanker transporting oil from the Trans-Alaska Pipeline System (TAPS) to a U.S. port. Except for Canadian residents bringing claims against a TAPS-related spill, the claimant must show that damage recovery is either authorized by treaty or agreement between the U.S. and the claimant's country or that a comparable settlement would be available in that country for U.S. claimants.

Oil Spill Liability Trust Fund

The OPA establishes an Oil Spill Liability Trust Fund, administered by the U.S. Coast Guard, to pay for removal costs and damages not recovered from responsible parties. With certain exceptions, no claim may be asserted against the Fund unless it is first presented to the responsible party. If the responsible party denies liability, or the claim is not settled within 90 days, the claimant may either commence an action in court, or present the claim to the Fund. No claim against the Fund may be approved while an action for that claim against the responsible party is pending in court.

Fund monies will be supplied by a five-cent-per-barrel fee on oil. For any single spill incident, the total amount available from the Fund is limited to $1 billion, of which no more than $500 million may be used to compensate for damages to natural resources. Claims against the Fund for removal costs must be made within six years after the completion of the removal action. Claims for property damages must be made within three years of the date of discovery of the loss. Claims for natural resource damages must be presented by the later of: (1) three years from the date of discovery of the loss; or (2) the date of completion of the natural resource damage assessment.

International Protocols

The final OPA, unlike earlier bills, does not provide authority to implement two 1984 international agreements on liability and compensation. The Act merely expresses a "sense of the Congress" supporting an international regime. When President Bush signed the OPA into law, he urged Congress to ratify and implement the international protocols.

Increased Federal Response Authority and Penalties

Section 4201 of the OPA amends section 311(c) and 311(d) of the Clean Water Act and, in turn, requires the Federal government to revise the NCP. The OPA amendments require the Federal government to "ensure effective and immediate removal of a discharge, and mitigation or prevention of a substantial threat of a discharge, of oil or a hazardous substance" into the navigable waters of the U.S., adjoining shorelines, and the exclusive economic zone. For spills large enough to pose a substantial threat to public health or welfare, the Federal government is now required to direct all public and private efforts to remove the discharge or to mitigate or prevent the threat of the discharge.[3] To facilitate and expedite emergency responses, the Federal government is exempted from laws governing contracting procedures and the employment of personnel.

Another amendment to section 311(c) of the Clean Water Act provides limited immunity for individuals involved in oil spill cleanup. The limited immunity applies not only to those working under the direct orders of the Federal On-Scene Coordinator, but to anyone rendering care, assistance, and advice consistent with the overall objectives of the NCP.[4] The intent of the OPA is to enable the Federal government to direct responses that are both immediate and effective.

Under the new section 311(d), the NCP is required to include procedures and standards designed to respond to a worst-case discharge of oil and for mitigating or preventing the threat of such a discharge. In the case of a vessel, a worst-case discharge is defined as a discharge in adverse weather conditions of the vessel's entire cargo. For facilities, the term is defined as the largest foreseeable discharge in adverse weather conditions. The Conference Committee notes that the general phrase "largest foreseeable discharge" is intended to describe an incident that is worse than either the largest spill to date or the maximum probable discharge.

Stricter Penalties

The OPA includes stricter penalties for discharges of oil or hazardous substances and other violations of the Clean Water Act. Section 4301(a) amends section 311(b)(5) of the Clean Water Act to increase the penalties for failure to notify the appropriate Federal agency of a discharge. The fine is increased from a maximum of $10,000 to a maximum of $250,000 for an individual or $500,000 for an organization. The maximum prison term is increased from one year to three years (or, in the case of a subsequent conviction, to five years).

Section 4301(b) of the OPA amends section 311(b)(6) of the Clean Water Act to authorize a civil judiciary penalty of $25,000 per day of violation or $1,000 per barrel of oil or unit of reportable quantity of hazardous substance discharged. Failure to comply with a Federal removal order can result in civil penalties of up to $25,000 per day of violation or three times the resulting costs incurred by the Fund.

Expanded Spill Preparedness Activities

Another major lesson learned during the *Exxon Valdez* cleanup was that the nation was inadequately prepared to respond rapidly and effectively to catastrophic oil spills. Section 4202 of the OPA therefore establishes a new planning and response system under section 311(j) of the Clean Water Act. The new system consists of a National Response Unit, Coast Guard strike teams, Coast Guard District Response Groups, Area Committees, Area Contingency Plans, and vessel and facility response plans.

The National Response Unit is to be established by the Coast Guard at Elizabeth City, North Carolina and will: (1) compile and maintain a comprehensive list of spill removal resources, equipment, and personnel that is available worldwide and within proximity to specifically designated areas; (2) coordinate use of private and public personnel and equipment to remove a worst-case discharge or to mitigate or prevent the threat of such a discharge; (3) administer Coast Guard strike teams to provide technical assistance, guidance, and training at the request of an On-Scene Coordinator; and (4) review and maintain on file area contingency plans. Implicit in the "coordinating" mission of the National Response Unit is the need for the Federal government to avoid duplicating private initiatives, such as the Marine Spill Response Corporation, a petroleum industry-financed consortium which is establishing response centers around the U.S.

The OPA also requires the President to designate areas for preparation of Area Contingency Plans. Area Committees, composed of Federal, State, and local officials, must prepare and submit these plans by February 1992. Response Groups are to be established in each of the ten Coast Guard Districts to coordinate equipment used for spill response activities and to review Area Contingency Plans.

Owners and operators of facilities and vessels have a major responsibility for preparedness. The OPA amends section 311(j) of the Clean Water Act to add requirements for the preparation and review of facility and tank vessel response plans. Under these amendments, the Federal government is required to issue regulations requiring the owner or operator of a vessel or facility to "prepare and submit to the President a plan for responding, to the maximum extent practicable, to a worst case discharge, and to a substantial threat of such a discharge of oil or hazardous substance." This requirement applies to all tank vessels and offshore facilities, as well as to any onshore facility that, "because of its location, could reasonably be expected to cause substantial harm to the environment by discharging into or on the navigable waters, adjoining shorelines, or the exclusive economic zone." OPA section 4202(b) requires the Federal government to issue these vessel and facility response plans by August 1992.

The facility response plans are required to meet certain standards. In particular, the plans must:

- Be consistent with the requirements of the NCP and Area Contingency Plans;
- Identify the qualified individual having full authority to implement removal actions, and require immediate communications between that individual and the appropriate Federal official and the persons providing personnel and equipment;
- Identify and ensure by means of contract or other means approved by the President the availability of private personnel and equipment necessary to remove to the maximum extent practicable a worst case discharge (including a discharge resulting from fire or explosion), and to mitigate or prevent a substantial threat of such a discharge;
- Describe the training, equipment testing, periodic unannounced drills, and response actions of persons on the vessels or at the facility, to be carried out under the plan to ensure the safety of the vessel or facility and to mitigate or prevent the discharge, or the substantial threat of a discharge;
- Be updated periodically; and
- Be resubmitted for approval of each significant change.

After February 1993, any vessel or facility required to submit a response plan may not handle oil unless the plan has been submitted to the Federal government.

Spill Prevention Measures

In addition to the provisions designed to prepare for large spills that do occur, the OPA contains several provisions that seek to prevent spills from happening at all. The major spill prevention features of the OPA are double-hull requirements for most new vessels, stricter licensing requirements for vessel personnel, new manning and safety standards, and several measures specifically related to Prince William Sound. The influence of the *Exxon Valdez* incident is particularly evident in the spill prevention provisions of the OPA, most which address the factors cited as having contributed to that accident.

The U.S. Coast Guard has estimated that a double hull on the *Exxon Valdez* would have reduced the sized of the spill by 50 percent, or 5.5 million gallons. Under the OPA, all newly-constructed tank vessels must be equipped with double hulls, with the exception of vessels used only to respond to discharges of oil or hazardous substances. In addition, newly constructed tank vessels less than 5,000 gross tons are exempt from the double-hull requirement if they are equipped with a double containment system proven to be as effective as a double hull for the prevention of a discharge of oil. Existing tankers without double hulls are to be phased out by size, age, and design beginning in 1995, and are required to be escorted by two towing vessels in specially designated high-risk areas. Most tankers without double hulls will be banned by 2015.

To ensure that the Coast Guard can identify vessel personnel with motor vehicle offenses related to the use of alcohol and drugs, the OPA requires anyone applying for a license, certificate of registry, or merchant mariners' document to provide a copy of his driving record obtained from the National Driver's Registry. Applicants must also submit to drug testing. Licenses, certificates of registry, and mariners' documents are to be renewed every five years, so personnel can be retested for evidence of drug and alcohol abuse or related convictions. The inclusion of these provisions reflects the perception that alcohol impairment may have contributed to the grounding of the *Exxon Valdez*.[5]

The OPA also requires that new vessel manning standards be set, both for U.S. and foreign vessels. For U.S. vessels, licensed seamen are not permitted to work more than 15 hours in any 24-hour period, or more than 36 hours in any 72-hour period. Forthcoming regulations will designate the conditions under which vessels may operate with the autopilot engaged or the engine room unattended. Crewmembers also must be trained in the maintenance of the navigation and safety features of the vessel. For foreign tank vessels, a Coast Guard review will determine whether vessel safety practices are at least the equivalent of U.S. requirements. Vessels that do not satisfy this standard will be prohibited from entering U.S. waters. These new requirements, inspired by issues raised in the investigation of the *Exxon Valdez* spill, should lead to better trained and better rested crews on tank vessels.

Finally, the OPA contains several provisions aimed at preventing future spills in Prince William Sound. Among the most significant of these, an automated navigation light is be placed on Bligh Reef, upon which the *Exxon Valdez* ran aground. In addition, all tank vessels in Prince William Sound are required to be under the direction and control of a pilot, licensed by the Federal government and the State of Alaska, who is not a member of the crew of the vessel.

Research and Development

The OPA also mandates the establishment of an interagency committee to coordinate oil pollution research, technology development, and demonstration. Technologies that may be developed include booms, skimmers, and containers for temporary storage of oil during recovery activities; chemical treatment methods; the introduction of microorganisms or nutrients; and the use of aircraft and remote sensing in spill cleanup and monitoring activities.

Conclusion

The Oil Pollution Act of 1990 is a comprehensive law that will affect virtually every aspect of the transportation, storage, and cleanup of oil in the United States. Although less than a year has passed since President Bush signed the legislation into law, the repercussions are already being felt. Until all of the regulations required under the OPA have been promulgated, the full impact of the legislation will not be known.

Notes

1. The NCP, which is codified in Part 300 of Title 40 of the Code of Federal Regulations, is the Federal government's blueprint for evaluating and responding to releases of oil and hazardous substances.

2. The "exclusive economic zone" is the zone contiguous to the territorial sea extending 200 miles from the shore, established by Presidential Proclamation 5030, March 10, 1983.

3. According to the Conference Report on the legislation, the public health or welfare of the U.S. includes, but is not limited to fish, shellfish, wildlife, other natural resources, and public or private shorelines and beaches.

4. Once a spill is reported to the Federal government, it is the On-Scene Coordinator, or OSC, who determines the status of the response and monitors the situation to determine if greater Federal involvement is necessary. The OSC ensures that the cleanup is appropriate, timely, and minimizes environmental damage.

5. National Transportation Safety Board, Marine Accident Report - Grounding of the U.S. Tankship Exxon Valdez on Bligh Reef, Prince William Sound, Near Valdez, Alaska, March 24, 1989, National Transportation Safety Board, Washington, D.C., p. 170, 1990.

Citizens' Involvement in Monitoring Alyeska Pipeline in Prince William Sound

By

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One of the major lessons learned by the people who live in the region of Alaska most directly affected by the Exxon Valdez spill is that oil and gas transportation is a risky business and the people who bear the burden of that risk MUST be involved in decisions regarding oil and gas transport.

HISTORY OF RCAC'S DEVELOPMENT FROM THE CITIZENS' PERSPECTIVE

The Regional Citizens' Advisory Council (RCAC) was formed following the spill. The State of Alaska required Alyeska Pipeline Service Company, which operates the pipeline and the terminal at Valdez, to submit an aggressive new spill prevention and response plan for Prince William Sound after the spill. The establishment of an independent regional citizens' advisory group is part of that plan.

Formation of the RCAC was a cooperative effort between Alyeska and citizens of the region affected by the oil spill. This effort was guided by the recognition that participation of local citizens is essential if environmental impacts from the operation of the Trans Alaska Pipeline System Terminal at Valdez are to be minimized.

Members include representatives of communities throughout the area affected by the spill, as well as Alaska Native villages and corporations, the commercial fishing industry, conservation organizations, the state chamber of commerce, and regional aquaculture associations. The members came together in June 1989 for two purposes: to review Alyeska's revised oil spill prevention and response plan for Prince William Sound, and to develop a plan to form a permanent citizens' oversight group to monitor operation of the Valdez terminal and oil tanker traffic served by the terminal.

After seven months of intense negotiations, RCAC signed a contract with Alyeska Pipeline Service Company that provides annual funding of $2 million for RCAC and access to the terminal and information.ap

for as long as oil flows through the Trans Alaska Pipeline. It also eliminates the company's ability to take disputes with RCAC about the contract to court, but instead mandates that it must enter into arbitration. This significant and precedent-setting document is clearly an acknowledgement by the oil industry that the public must play an active role in corporate decision making. The citizens of the region, through the council, now have access to and are able to influence operations of the nation's largest oil terminal to reduce the facility's present and future environmental impacts. The extent of this influence is unknown. It has yet to be fully tested, but at least the door is open.

The contract is also significant because it sets a precedent for how the oil industry and industry in general operate in the rest of the nation and world. The RCAC-Alyeska contract creates an innovative relationship between community and industry and consists of more than legalities; the contract is a strong and mutual commitment to good citizenship.

Independence is a critical part of this contract. "The Council is willing to participate in the citizens' advisory process for the public and Alyeska on a permanent basis only on the conditions that it be truly independent from Alyeska and that Alyeska provide the Council with a permanent source of adequate funding." (Alyeska/RCAC contract)

The contract has attracted wide attention. RCAC has had requests for copies of the contract from citizen groups in Santa Barbara, Puget Sound and other areas where these companies have shipping facilities. RCAC members also met with representatives of New York State who were interested in using the RCAC model to help them site and monitor operations of a nuclear waste facility, and were invited to Rhode Island to facilitate a panel discussion on "Citizen Empowerment in Oil Spill Prevention" at an international oil spill conference.

The first major RCAC action was to review the new Prince William Sound Oil Spill Prevention and Response Plan. During the review process, which included reviewing two draft versions of the document, RCAC members invested some 5,000 person hours in a thorough evaluation of the plan. After a series of meetings with Alyeska, about 75% of our comments were incorporated into the final plan submitted to the Department of Environmental Conservation (DEC) for approval. (The rest of RCAC's recommendations fall within the regulatory purview of the Coast Guard and DEC.) The primary components of the new plan include:

a ship escort and response vessel system or SERVS designed to safeguard tankers and reduce the chances of another major spill; use of the standard Incident Command System employed in fire fighting and other emergency response programs; and use of local fishing boats and local expertise in the response strategy.

The plan is a dramatic improvement over the existing plan and will ensure greater protection for Prince William Sound and the Gulf of Alaska. In addition, it serves as a standard that can be used to measure contingency plans for oil industry development in other areas of the state such as the Beaufort and Bering Seas.

RCAC's chosen course of action for developing a permanent citizens' oversight group was to incorporate as a non-profit and enter into a contract with Alyeska that requires Alyeska to fund the citizens' group as well as provide access to the terminal and establishes a formal and verifiable process for ensuring that the advice provided by the citizens' group is given serious consideration by the company.

RCAC was chartered as a non-profit corporation by the State of Alaska on December 26, 1989. Contract negotiations with Alyeska were completed February 7, 1990, and a contract was signed by RCAC members and Jim Hermiller, president of Alyeska. The contract provides RCAC with the same level of access to the terminal provided all state and federal regulatory agencies.

RCAC's structure was modeled in part on a successful citizens' oversight group at Europe's largest oil terminal west of the massive North Sea oil field at Sullom Voe in the Shetland Isles. RCAC members have visited Scotland to meet with members of the Sullom Voe Oil Terminal Environmental Advisory Group (SOTEAG) and members of SOTEAG have visited Alaska to meet with members of RCAC.

COUNCIL/COMMITTEE STRUCTURE

A sixteen member board and staff accomplishes its goals primarily through three working committees:

Port Operations and Vessel Traffic Systems
Oil Spill Prevention and Response
Terminal Operations and Environmental Monitoring

These broad-based citizens committees monitor oil spill prevention, response, and cleanup planning, Valdez terminal operations and environmental monitoring, Port Valdez operations and vessel traffic systems, and legislation.

The Scientific Advisory Committee, comprised of scientists and technical experts, reviews research proposals and advises the working committees and the council on technical issues.

ROLE OF RCAC

RCAC's mission statement defines the council's role: "To ensure the safe operation of the Trans Alaska Pipeline Terminal and the crude oil tankers served by the terminal so that environmental impacts associated with the terminal and tanker fleet are minimized."

RCAC acted on two portions of the federal oil spill legislation passed by Congress in 1990. The first was to rewrite the title of the legislation that establishes federal citizens' oversight committees for Prince William Sound and Cook Inlet. The RCAC language broadens the powers of the federal councils and gives opportunity for greater local citizen involvement in the establishment of the councils. The legislation allows RCAC to apply to become the federally recognized council for Prince William Sound and establishes a similar council for Cook Inlet. The RCAC sought this presidential certification in October, 1990.

During RCAC's annual meeting in March of this year, Senator Frank Murkowski presented the RCAC with our certification from President George Bush to be this federally mandated regional citizens' advisory council.

Throughout last year's legislative session in Alaska, RCAC and its members worked hard for the passage of bills that strengthened oil spill prevention and response strategies, increased authority of the Department of Environmental Conservation to regulate oil industry activities, increased financial responsibility requirements for oil industry facilities, and allowed citizens to sue for non-compliance with state environmental laws. Among those that passed are bills that increase penalties for oil spills, increase the state's readiness to respond to oil and hazardous substance spills, strengthen contingency planning requirements, increase financial responsibility for oil industry facilities, and create a statewide citizens' oversight council for oil spill prevention and response.

The RCAC-Alyeska contract specifies that RCAC committees will perform independent research and monitoring of oil spill prevention and response efforts, tanker safety, and environmental effects of terminal operations. RCAC uses this information to develop recommendations for environmental safeguards to Alyeska and government regulatory agencies.

The council through its committees has heavily influenced the Alyeska oil spill contingency plan, critically reviewed the Coast Guard vessel tracking systems and the tanker fleet, commissioned scientific studies of pollution in Port Valdez, participated in oil spill drills, and testified at legislative oversight hearings on the TAPS trade.

BENEFITS OF A CITIZENS' COUNCIL FOR INDUSTRY

Council and committee members increase public involvement and understanding by educating themselves and the people in the general public who become knowledgeable about industry issues and technical information. These citizens through the committee and council process provide detailed studies, research, and comments in specific subject areas. The members of the committees also participate in various technical working groups with industry and regulators.

There now exists a strong mechanism for ensuring a sound relationship and understanding between industry and the public. The public involvement process exhibited by the formation of the Regional Citizens' Advisory Council is a successful model for other companies and industries in the nation and around the world. Alyeska's investment in time, effort and money has produced an increased level of knowledge, trust and awareness. An educated citizenry will better understand complex issues; as concerns continue to mount about the impact of industry on the environment, a cooperative effort such as this is an excellent way to incorporate feedback from the public.

We must work at preventing oil spills with the same degree of effort we devote to preventing nuclear accidents and airline crashes. We must also devote a greater effort to working cooperatively together to solve transportation problems. All too often we have been adversaries working against one another rather than citizens cooperatively seeking progress and improvements.

PUBLIC INVOLVEMENT IN MARINE SAFETY

The Relationship between the Prince William Sound Regional Citizens' Advisory Council

and the

U.S. Coast Guard

by
CDR Ed Thompson, U.S. Coast Guard

Background. The Oil Pollution Act of 1990 (OPA-90) was signed the eighteenth of August 1990. It marked a renewed commitment on the part of Congress and the American people to deal with the environmental hazards involved in shipping oil on the waters of the USA. The law is divided into nine titles(chapters) that deal with the myriad aspects of the legal and operational framework of the oil and shipping industries in this country. Title V of the law is named the Prince William Sound Provisions. Section 5002 of this title deals with Terminal and Tanker oversight and monitoring. Some quotes from the "Findings" that lead this section should be illustrative:

" (B) many people believe that complacency on the part of the industry and government personnel responsible ...was one of the contributing factors to the EXXON VALDEZ oil spill;

(C) one way to combat this complacency is to involve local citizens in the process of preparing, adopting, and revising oil spill contingency plans;

(D) a mechanism should be established which fosters the long term partnership of industry, government and local communities in overseeing compliance with environmental concerns in the operation of crude oil terminals; ...

(G) the present system of regulation and oversight ... has degenerated into a process of continual mistrust and confrontation;

(H) only when local citizens are involved in the process will the trust develop that is necessary to change the present system from confrontation to consensus; ..."

With these words, the Congress of the United States went on to outline a structure for citizen oversight in Cook Inlet and Prince William Sound, Alaska. These Regional Citizens' Advisory Councils (RCAC's) are formed and certified under the authority of this Act.

The mandate of these RCAC's, as described in the Law, goes well beyond participation in the development of the Alyeska Oil Spill Contingency Plans. The RCAC is involved in every aspect of the operation of the terminal, vessel movements, and tank vessel safety. I have paraphrased section 5002 (d) (6) that lists the duties of the RCAC below.

1. Monitor and provide advice on the regulation, operation and maintenance of oil terminal facilities and crude oil tankers.

2. Monitor the environmental impacts of the above facilities and tankers.

3. Review the Contingency Plans for the terminal and tankers.

It is evident that the law gives the RCAC broad involvement in the operation of the terminal and the tankers that service it. The law goes further, in the same section:

> "...each federal agency, department or other instrumentality shall, with respect to all permits, site specific regulations, and other matters ... consult with the ... council..."

The intent is evident. The Coast Guard has been the lead federal agency in establishing a relationship with the RCAC.

History of the RCAC/USCG Relationship. The Marine Safety Office in Valdez has been the point of contact for the Coast Guard's interaction with the RCAC. Our first tentative contact was made in the Spring of 1990. The RCAC (then called the Regional Citizens' Advisory Committee) was in the process of finalizing their contract with Alyeska Pipeline Services Company. I arrived uninvited to my first meeting with the RCAC, but I was warmly welcomed. The Council then proceeded to question me for 20-30 minutes on the operation of the VTS and the status of various upgrades of the system. I suppose it went well since I was invited to the next and subsequent meetings. Since that first contact, a representative of the Marine Safety Office has been at most meetings of the Council and its Committees. Our relationship has been most productive. Our exchange of views has been guided by the following:

1. Honesty

2. We're not afraid to announce bad news or agree to disagree.

3. We place the maintenance of a relationship above any problems or disagreements which may arise.

4. We are as responsive to the RCAC's needs as possible and don't place bureaucratic impediments in the way to slow information flow.

This approach has worked well. The RCAC, to their credit, has acted in a professional manner in all their dealings with the Coast Guard. They listen well, are quick studies on issues unfamiliar to them, and do their homework thoroughly before expressing an opinion publicly.

During December of 1990, MSO Valdez initiated a recommendation for the certification of the Prince William Sound RCAC. The President signed the certification on the twenty first of March 1991. The certification was presented to the RCAC by Rear Admiral CIANCAGLINI, USCG two days later at a public ceremony in Valdez.

Future of the RCAC/USCG Relationship. What has worked well in the past will likely carry us into the future. Continued honest and open dialog coupled with the trust we have developed so far will reap benefits for a long time to come.

The RCAC is an involved and influential body. Its Congressional mandate helps; but more importantly, we realize the truth of the Findings. An educated and involved citizenry is more likely to be an ally in a crisis as well as enhance the day to day operation of the Port. It is imperative that all the organizations and companies involved get used to answering their questions and educating them.

It's not all work for industry and the agencies and no benefit, RCAC members are productively working with industry and government on the development of the Alyeska contingency plan. They are making their presence known in all aspects of port operations, vessel traffic and tank vessel safety issues. It should be noted that the members of the RCAC are not compensated for their time. For the members who contribute countless hours to their tasks, it's an expression of civic responsibility that deserves great merit.

Membership. Marine Safety Office Valdez has petitioned the Prince William Sound RCAC to become a nonvoting member, as provided in OPA-90. We look forward to a closer, and ever more productive relationship in the future.

CITIZENS ADVISORY CONCEPT AT ALYESKA
PIPELINE SVC. CO.

by

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CITIZENS ADVISORY CONCEPT AT ALYESKA PIPELINE SVC. CO.

May 7, 1991

HISTORY

On March 24, 1989, the day the Exxon Valdez ran aground on Bligh Reef in Prince William Sound, the oil industry in Alaska changed: specifically, the days of keeping the "public" on the outside were over. Jim Hermiller, who came to Alaska after the event and became President and CEO of Alyeska Pipeline Service Company (Alyeska) in May of 1989, recognized the problems associated with little or no public involvement and set about to change Alyeska's policy. In the latter part of 1989, he began the process of negotiating a contract with a group of citizens from the impacted area of the Exxon Valdez spill, a contract which eventually was agreed to and signed on February 8, 1990. This same group was later certified, on March 21, 1991, under the federal Oil Pollution Act of 1990 (OPA-90), as the "Prince William Sound Citizens' Advisory Council."

CORPORATE RESPONSIBILITY

It would be inappropriate to imply that Alyeska's way of cooperating with citizens in its business decisions is right for every company. Alyeska can, however, state unequivocally that "it works for us." Because of the significant negative public reaction to the spill and the spill response, it became quite clear that the citizens of the impacted area were not supportive of a major industry in their area and, in our view, were not supportive because they did not understand the "how" and "why" behind Alyeska's actions and operations.

It became equally clear that it was in the company's best interests to provide accurate and timely information and to establish a "cooperative partnership" so that these citizens would have the opportunity to monitor our operations and to provide input into appropriate business decisions. It also appeared to us that it would be in our best interests to ensure, to the best of our ability, that this Council was "constituency based," i.e., that they were responsible to bonafide representative groups in the impacted area. We felt this would minimize the opportunity for individuals with personal agendas to target Alyeska for special treatment and would provide a reasonable level of assurance that these groups would function responsibly and in a productive fashion.

The Prince William Sound (PWS) Regional Citizens' Advisory Council (RCAC) was established to provide local involvement in the development and ongoing implementation of the PWS Tanker Spill Prevention and Response Plan. RCAC's function is also to provide monitoring and advisory functions regarding actual and potential environmental impacts of the Valdez Marine Terminal and Oil Tanker operations, and to the extent of Alyeska's ability to influence such matters, Valdez Port Operations and Prince William Sound Vessel

Traffic Systems. Alyeska's contract with the RCAC is for the life of the TransAlaska pipeline operation.

The RCAC is completely independent from Alyeska. Alyeska has no control over the operation of the Council nor do we have any right to membership. We feel strongly that the only way this process will work to the benefit of both parties is to assure complete independence. The RCAC is required to have broad regional representation from the communities in the impacted area including local governments, fishing groups, aquaculture, native associations, environmental organizations, and other special interest groups in the region.

Alyeska supports the RCAC with annual funding in the amount of $2,000,000 and may provide supplemental funding for special studies, including research and development. Alyeska also agreed to provide access to information and facilities equal to that of regulatory agencies.

BENEFITS OF RELATIONSHIP

Alyeska has benefited greatly from the relationship with the citizenry in the impacted area. While the RCAC membership represents a cross section of interests from the area, we have found that, in the main, their decisions and positions are studied, sound, and reasonable. Their input into specific operational and oil spill response plans has been productive. In fact, they have provided a most comprehensive and well thought out review of our PWS oil spill and response plan. Alyeska has adopted roughly 75% of their recommendations. While we don't agree on everything, we have found them to be quite supportive in several operational, regulatory, and legislative areas.

It is my opinion that the citizens of the region have benefited as much as Alyeska has from this new relationship. They now have the opportunity to work closely with executives and managers whose decisions have the potential of impacting their environment and lifestyles. They can provide input or raise objection to projects during the planning phase, make recommendations on how certain aspects might be improved or endorse actions where appropriate. Although Alyeska is not required to implement any of their recommendations, the company's contract with RCAC calls for timely response to their inquiries and a candid explanation of company positions. RCAC does not have regulatory authority nor are they considered in that context.

OBSERVATIONS

This has not been a completely troublefree relationship and process. The citizens of the area, while certainly now more supportive of our industry, are still not completely trusting, nor should they be, given their role as "monitoring citizenry." They are, as one might expect, still watching to see how much of a neighbor Alyeska will be, not just today or tomorrow but five, ten or fifteen years from now.

Alyeska is concerned about how much the RCAC is trying to handle. They have four significant committees with a half dozen objectives each. As in our company, "burn-out" is possible, and with their current workload, probable. We urge caution on their behalf.

Alyeska is also concerned that certain "committees" established to work on areas of Council concern are not specifically constituency based. It appears that some individuals appointed to these committees are able to work their individual agendas apart from concerns raised by recognized local entities.

CONCLUSION

This process is working for Alyeska. Citizen advisory councils are becoming a fact of life in many areas of the U.S.A. as required by OPA-90. I would suggest that if your operation has the potential for environmentally impacting a geographical area, it is time to establish a formal relationship with the citizens in your area. It is far better to do it before a catastrophic event takes place.

OIL POLLUTION IN THE ARCTIC MARINE ENVIRONMENT

by

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ABSTRACT

At a consultative meeting in Rovaniemi, Finland, the eight Arctic countries (USSR, USA, Canada, Iceland, Sweden, Denmark,Finland and Norway) initiated a project on the protection of the Arctic environment. The Arctic was in this context defined as the area north of the Arctic circle. In association with this work, information on inputs of petroleum hydrocarbons (PHC) to the Arctic has been collected. Data on indirect oil transport (atmosphere, ocean currents, rivers) have not been available. However, order of magnitude calculations indicate that the main contribution of PHC comes from river transport (estimated at 200.000 metric tons per annum). Measurements of hydrocarbon content in the water column, the sediment and the biota have also been collected. The data indicate that certain areas may be polluted by oil. High values of hydrocarbon concentration are reported from Siberian estuaries (up to 100µ/l in the Ob Gulf). However, different methods of analysis make it difficult to do comparative assessment of the reported values. The uncertainty of the available data strongly underlines the necessity of collecting new data on PHC concentrations. The Arctic countries are in this respect discussing a monitoring and assessment programme of the Arctic (AMAP) to establish an agreed state of all polluting parameters, including PHC.

1. INTRODUCTION

At the invitation of Finland, representatives of the eight countries bordering the Arctic region, Canada, Denmark, Finland, Iceland, Norway, Sweden, the Union of Soviet Socialist Republics and the United States of America met in Rovaniemi from 20 to 26 September 1989 for the

Consultative Meeting on the Protection of the Arctic Environment. The Arctic is in this context defined as all areas north of the Arctic Circle. At the meeting a common concern about the Arctic environment was expressed. This concern is based on recent studies that reveal an increasing presence of a number of contaminants in the Arctic ecosystem (Anon, 1989). An accelerating damage is occuring in these areas, previously pristine and untouched by man. Phenomena such as climate change, ozone depletion, acidification, Arctic haze, marine pollution and accumulation of toxic substances in the Arctic food chain are only now beginning to be understood.

In the discussions at the Consultative meeting a need for better information and scientific data on various environmental issues was expressed. It was therefore agreed that a series of reports on the state of the environment should be prepared, based on existing literature, concentrating on the main pollutans in different parts of the ecosystem. The reports were to be prepared through the co-operation of experts from all countries concerned, under the co-ordination of one of them. Norway was made responsible for reviewing the present state on oil pollution.

The Arctic (together with the Antarctic) environment represent the most stressed natural environment of all. It is caracterized by low temperatures, periodes with little or no daylight, permafrost and large areas with pack ice and permanent ice. The Arctic ecosystems are usually simpler than other systems, involving a lower diversity of species. This means that an extinction of a given link or large reduction of a population might be serious. Many of the animals grow slowly, mature late and either produce relatively few young during each breeding season, or breed only once annually (Chia, 1970).

Due to the low temperatures biodegradation is slow and it is considered a minor factor in the removal of oil from shorelines and sediments. In addition the evaporation of volatile components is lower than in warmer areas. Therefore, oil spills, even minor leaks, present a more lasting problem in the Arctic than elsewhere.

We cannot fully evaluate the problem of oil pollution in the Arctic because we do not know enough about the fate of petroleum in the Arctic marine environment, or the possible effect of petroleum on the Arctic ecosystem. But from what we know, the Arctic is one of the areas most vulnerable to adverse impacts from chronic and acute oil pollution.

This article gives an overview of available data on inputs to and measurements on petroleum hydrocarbons (PHC) in Arctic marine areas. Information on inputs of PHC has been supplied by the eight Arctic countries.

2. OIL INPUTS TO THE ARCTIC REGION

PHC are loaded into the environment by several pathways like natural seeps, rivers, atmospheric inputs, ocean currents, sea disposal (dumping), and direct discharges from offshore petroleum activity, refineries, terminals and from shipping.

Little data on the magnitude of the PHC inputs from the different sources is available. The amount of information, and probably also the accuracy of the values estimated, varies considerably. We should bear this in mind when drawing conclusions from the data presented and making comparisons between sources and countries.

Most of the oil pollutants in the Arctic have their origin far south of the Arctic region. The information on these indirect sources (long range transboundary pollution) is scarce and most estimates must be based on numerical models, theoretical approaches or extrapolations from other measurable parameters. No estimates of indirect oil transport to the Arctic were available from any of the eight Arctic countries when data was collected to the status report on oil pollution in the Arctic environment (see Introduction). But as a part of preparing the report estimates of riverine and atmospheric inputs were made.

2.1 The Riverine Input

No data exist on PHC concentration in Arctic rivers. However, Soviet measurements from the Siberian river estuaries are available (Melnikov, et al., 1990). Based on these data and the fact that Siberian rivers contribute about 60% of the total fresh water discharge into the Arctic, the riverine input has been estimated (Anon, 1990). The annual river transport of petroleum hydrocarbons to the Arctic marine environment was estimated to be in the order of 200 000 metric tons (Table 3).

The Soviet measurements in the major Siberian river estuaries in the period 1983 - 1989 show little annual variations (tab.6). Melnikov et al. (1990) state, however, that "since 1987 the pollution level in the rivers of the region has become stable".

2.2 The Atmospheric Input

The atmospheric input of PHC to the Arctic has been estimated on the basis of an assumed correlation (constant ratio) between the content of sulphur and PHC in precipitation, and measurements of PHC in snow cover in the Siberian Arctic (Anon, 1990). The annual input of PHC from the atmosphere is estimated to 80.000 metric tons (40.000 metric tons to the marine areas and 40.000 metric tons to the terrestrial areas).

Based on this model for calculation, the data on sulphur content in precipitation and PHC-content in snow cover in Siberian seas indicate that the atmospheric input of PHC has been relatively stable during the last 5 years (Anon, 1990).

2.3 Direct Discharges

Reported oil spills into the Arctic marine environment are presented in Table 1. All figures in the table are subject to uncertainties, the extent of which are variable and difficult to quantify. These data are, however, more reliable than those for indirect sources.

No specified Soviet data on oil spills into the Arctic are available. The total USSR input value of 200 metric tons per year is based on Melnikov et al. (1990), who state that this is the annual amount "of PHC entering the Arctic Ocean waters in summer months due to human activity".

Table 1. Reported oil spills into the Arctic marine environment. Estimated mean values (metric tons per annum).

	Country				
Sources	Canada	Greenland	Norway	USA	USSR
Vessel oil spills	83	-	40	43	-
Oil terminals	11	0	0	-	-
Offshore production		0	0	≈ 0	-
Other accidental or illegal discharges		-	30	≈ 0	-
Total	94	0	70	44	200

Note: Where no values have been supplied, this is indicated by a dash (-) The Canadian data are annual means for the 5 year period 1984-1988; Norway: 4 years, 1986-1989; USA: 5 years, 1985-1989. The Soviet data represent both continuous discharges and spills.

The oil input into the Arctic region from spills varies considerably from year to year and from one region to another. Figure 1 shows the total amount of hydrocarbon spills entering the Arctic marine environment from Canada in the years 1972-1988. The Canadian data are for all marine areas north of the Canadian mainland. The data therefore include a potential contribution to the (unknown) marine transport of oil pollutants to the region north of the Arctic Circle. In this connection, oil spills into other adjacent ocean areas are of interest. These data are given in Table 2.

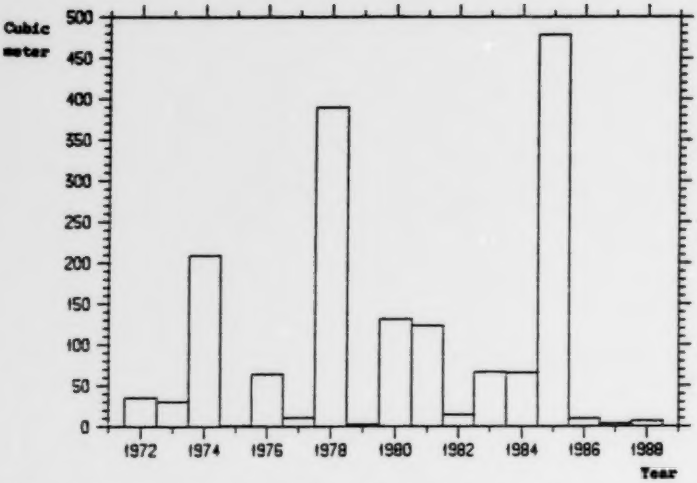

Figure 1. Annual hydrocarbon spills entering Arctic marine environment from Canada. (Sackmann, 1990).

Similar large year-to-year variability can be seen in the Alaskan data on acute oil spills to the Beaufort Sea and the Bering Sea. The USA mean annual value of 44 metric tons is almost entirely due to a single spill of 217 metric tons of fuel oil. (Hull rupture in a tank barge in the Beaufort Sea in 1988.) Mean values may thus be misleading, smoothing out rather large year-to-year variations.

Table 2. Reported oil spills into marine areas adjacent to the Arctic

Bering Sea *	767 metric tons per annum
Bering Strait	* 0 metric tons per annum
Icelandic Waters	129 metric tons per annum

* The main contribution to the value for the Bering Sea is one accidental discharge of 3 660 metric tons of diesel oil in 1989.

Regarding a possible marine oil transport into the Arctic, it should be noted that the mean inflow through the Bering Strait is estimated to 1 sv (= 1 million m^3/s) (Coachman and Barnes, 1961; Pickard, 1975).

The largest reported Icelandic oil spill occurred in 1985 when an avalanche hit an oil storage tank, and about 480 metric tons of heavy fuel oil were lost (Augustsson, 1990).

No data is available on other sources of direct input to the Arctic environment.

2.4 Conclusions

Table 3 lists the estimated inputs of oil to the Arctic region. The stated values represent the best available estimates, but some are highly uncertain. However, the relative proportions are probably representative, showing the order of magnitude of each source.

The main inputs of PHC to the Arctic region seems to come from continuous discharges, and rivers in particular seems to be the main contributor. The major Arctic rivers have larger parts (60-70%) of their catchment area to the south of the Arctic circle. For instance the river Ob and its tributaries originate at 45° N. Because of this a considerable part of the northern world's contamination will eventually reach the Arctic.

In comparison with the total annual oil input, reported accidental discharges of oil are small. On a local and regional scale, however, such acute spills represent the largest threats.

The full extent of natural seepage into the Arctic is not known. The input is probably low compared with other contributors and is considered neglectible as a pollution source (Clark and Finley, 1982, State Pollution Control Authority, Norway, 1990).

Table 3. Estimated total oil input to the Arctic marine environment (metric tons per annum).

Marine transport	No agreed estimate
Atmospheric transport	40 000
River transport	200 000
Reported spills (Table 2.2)	400
Oil and gas industry,	Not available
seepage, sewage, dumped waste	Not available

2.5 Future Loadings

The expected reduction of oil discharges from the operation of ships because of improved procedures and more stringent discharge criteria may be more than counterbalanced if the total ship volume increases. In this connection the plans for opening the North-East Passage (the Northern Sea Route) on a year-round basis should be critically evaluated. In order for this alternative route to be of commercial interest, the necessary increase in cargo volume is estimated to be at least 4-5 times the current volume, which is about 6 million metric tons per year. An equivalent increase (4-5 times) of oil discharges from ships must be expected, if no operational or structural improvements are prescribed.

Prospective exploration, drilling and production of oil and gas may also cause an increase in oil discharges in the Arctic. Estimated future loadings of hydrocarbons to Canadian offshore areas from petroleum exploration and development are 430 metric tons (per year?) including 23 metric tons from drill cuttings and 400 metric tons in produced water. This Canadian estimate is of the same order of magnitude as today's total oil input from reported spills (Table 3).

Besides the Canadian offshore projects, similar drilling programs exist for the Alaskan Arctic. Oil and gas activity in the Barents Sea has been in progress since 1980 (Norway) and 1982 (USSR). However, estimates on future loadings from these petroleum related activities are not available.

3. THE HYDROCARBON CONTENT OF THE WATER COLUMN, THE SEDIMENTS AND THE BIOTA

Although the pollution level is low in the Arctic region compared to other areas, petrogenic and biogenic hydrocarbons are continuously introduced into the marine environment through biosynthesis, geochemical processes, and human activities. The petroleum is subsequently distributed between the water column, the sea-bottom sediment, and the biota, resulting in a low, but significant hydrocarbon level in all the three phases involved.

These levels have only been determined accurately for scattered samples collected at various localities in the Arctic region and have been collected over a rather limited period of time. Strong regional variations may be observed in the background hydrocarbon levels. As a consequence it is rather difficult to distinguish regional trends and draw definite conclusions with respect to contaminant levels. The collected data are discussed and summarized separately for each of the three phases (tab.

3-6). All the data are standardized as far as possible with respect to the units and the methods of calculation.

3.1 The Water Column

In general, low levels (ng/l or nl/l) of hydrocarbons have been found in the sea areas north of Alaska, Canada and around Greenland. Shaw (1977), however, measured relatively high concentrations in the American part of the Beafort Sea (up to 27 µg/l). In the Siberian coastal waters high concentrations of hydrocarbons have been measured in several areas. In the Kara Sea Basin, measured PHC concentration was up to 90 µg/l in the Yenisey Bay and 100 µg/l in the Ob Gulf. Local sones with high concentrations of PHC was also found in the Laptev sea and in the East-Siberian Sea (up to 50 µg/l).

The hydrocarbon data have been obtained with different analytical methods and for different types of hydrocarbons. The results from the USSR are difficult to compare with the rest of the data, since they represent bulk fractions of hydrocarbons analysed by IR-spectrophotometry. This method is less sensitive than others and does not distinguish between petrogenic hydrocarbons, biogenic hydrocarbons and lipid materials. The detection limit of the method is 30 µg/l, and thus no information is obtained about lower concentrations. Even with these reservations, the data indicate that there is a relatively high level of oil pollution in Siberian estuaries. The concentrations of both total petroleum fractions and high boiling compounds are quite similar in the five areas sampled. The year to year variations shown in Table 6 do not indicate significant changes in concentrations during the period from 1982 to 1989.

A comprehensive study has been made of total HC concentrations in the water column of different areas in the North Sea (Aquatic environment monitoring report, 1990). Compared with the results of this study, which range from 0.2-47 µg/l (75% of 397 results were less than 5µg/l), the data presented in the this article are generally much lower (with exception of the Siberian data). However, this article describes data from relatively narrow HC boiling point ranges, so that a direct comparison is not possible.

3.2 The Biota

Table 4 presents available data on the hydrocarbon content of Arctic marine organisms.

Paraffin and non-polar concentrations vary between 0.1 and approximately 29 mg/kg wet weight for most samples. Because of variations in analytical methods, comparison within the present data set and with results from studies in other parts of the world is difficult. However, the Arctic biota HC levels seem to be in the lower part of the range of HC concentrations measured in marine biota. HC in fish liver tissue and muscle from background areas in the North Sea has been detected in the range of <0.1 - 600 µg/g dry weight (Hasle et al., 1987; Bowler et al., 1986; Bowler et al., 1987; Johnsen et al, 1988a). No data is available from Siberian waters.

3.3 The Sediments

Data on the hydrocarbon content of Arctic marine sediments are listed in Table 5. The sediment results reported may be related either to wet or dry sediment weight, and it is thus difficult to compare the data available. The sediment depth is unknown for more than half of the data, and this may also lead to variation in the results.

In general, low levels of HC have been found in the few areas we have data from (5-17µg/g wet weight, 0.06-12.5µg/g dry weight)(see Table 5). These results agree well with the HC levels measured in non-contaminated marine sediments in other parts of the world. For instance, the background HC concentrations of sediments in the Norwegian sector of the North Sea is normally less than 10 µg/g (Bakke et al., 1990). Wong et al., however recorded high concentrations in the Canadian part of the Beaufort Sea (up to 164 µg/g dry weight). A possible explanation of these results can be input of oil from natural seeps (Wong et al., 1976).

Table 6. presents the year to year variation of total petroleum hydrocarbons in Siberian seas' surface waters and snow.

4. CONCLUSIONS AND FURTHER ACTIONS

The most obvious conclusion one can draw from the available data is that further studies are necessary to reach a concensus on the magnitude of the PHC input to and the PHC content of the marine environment. Based on the available data, the Siberian estuaries seem to be relatively polluted by oil. The PHC concentrations reported from these areas are much higher than concentrations measured in polluted estuaries outside the Arctic. For instance, in the inner German Bight at the mouth of the Elbe and the Rhine, the measured concentrations are 5-25µg/l (Anon, 1987). The concentrations (mean values) reported from Siberian waters were <30-45µg/l (several measurements were in the range 70-100 µg/l). However, the different methodes makes it difficult, or impossible to draw conclusions.

Several possible actions are under discussion to follow up the work done so far on the Protection of the Arctic

Table 3. The hydrocarbon content of the water column in the Arctic

Location	Depth	Method of analysis*	Type of hydrocarbon	Hydrocarbon content	Reference
USSR (winter-spring 1989)					
Kara Sea	Surface	IR	Tot.petroleum	30.9 µg/l	Melnikov et al.(1990)
			High boiling	10.0 "	
Laptev	"	"	Tot.petroleum	33.7 "	Melnikov et al.(1990)
			High boiling	16.0 "	
East Siberian	"	"	Tot.petroleum	≤30.0 "	Melnikov et al.(1990)
			High boiling	15.0 "	
Chuckchi	"	"	Tot.petroleum	≤30.0 "	Melnikov et al.(1990)
			High boiling	14.0 "	
Central Arctic Basin	"	"	Tot.petroleum	≤30.0 "	Melnikov et al.(1990)
			High boiling	10.0 "	
Kara Sea	Sea ice	"	Tot.petroleum	31.8 "	Melnikov et al.(1990)
			High boiling	11.0 "	
Laptev	"	"	Tot.petroleum	≤30.0 "	Melnikov et al.(1990)
			High boiling	10.0 "	
East-Siberian	"	"	Tot.petroleum	≤30.0 "	Melnikov et al.(1990)
			High boiling	27.5 "	
Chuckchi	"	"	Tot.petroleum	45.0 "	Melnikov et al.(1990)
			High boiling	12.6 "	
Kara Sea	Snow	"	Tot.petroleum	37.9 "	Melnikov et al.(1990)
			High boiling	10.5 "	
Laptev	"	"	Tot.petroleum	33.7 "	Melnikov et al.(1990)
			High boiling	21.5 "	
East Siberian	"	"	Tot.petroleum	45.8 "	Melnikov et al.(1990)
			High boiling	32.4 "	
Chuckchi	"	"	Tot.petroleum	40.0 "	Melnikov et al.(1990)
			High boiling	33.3 "	
Central Arctic Basin	"	"	Tot.petroleum	35.5 "	Melnikov et al.(1990)
			High boiling	15.6 "	

(continued)

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* IR = IR-spectrophotometry

Table 3. continued. The hydrocarbon content of the water column in the Arctic .

Location	Depth (m)	Number of samples	Method of analysis*	Type of hydro-carbon	Hydrocarbon content**	Reference
Greenland						
Færingehavn	1	18	GC/MS	NPD***	5-220 ng/l	Ahnoff et al. (1983)
Færingehavn	10	2	GC	$n-C_{13}-C_{19}$	53-74 ng/l	Ahnoff et al. (1983)
Færingehavn	1	1	GC	"	52 ng/l	Ahnoff et al. (1983)
Open Sea	1	3	GC/MS	NPD	5 ng/l	Ahnoff et al. (1983)
USA-USSR						
Bering Sea	4	45	GC	Methane	70-200 nl/l	Shaw (1977)
Chukchi Sea	Surface	6	GC	THC	0.13-1.41 µg/kg	"
USA-Canada						
Beaufort Sea	Surface	14	GC	Saturates Unsaturates	0.05- 27.16µg/kg 0.04-0.83 µg/kg	Shaw (1977)
Southern Beaufort Sea	0-5	55	GC	C_1-C_4	43-563 nl/l	Wong et al. (1976)
"	10-35	20	GC	C_1-C_4	69-1155 nl/l	Wong et al. (1976)
"	48-70	9	GC	C_1-C_4	78-412 nl/l	Wong et al. (1976)
"	>100	2	GC	C_1-C_4	16-243 nl/l	Wong et al. (1976)
Arctic Ocean, Atlantic	Surface	32	GC	C_1-C_4	79-112 nl/l	Swinnerton et al. (1974)
Norway						
Norwegian Sea	Surface	56	GC	C_1-C_4	65-75 nl/l	Swinnerton et al. (1974)

* GC = Gas chromatography
GC/MS = Gas chromatography/mass spectrometry

** nl/l = 10^{-9} litre gas per litre seawater

*** Naphthalenes, phenanthrenes, dibenzothiophenes

Table 4. The hydrocarbon content of Arctic marine organisms.

Location	Organism	Method of analysis*	Type of hydro-carbon	Hydrocarbon content (mg/kg wet weight)	Reference
Arctic Ocean	Cod	GC	n-paraffins	1.26	Clark (1976)
Iceland	Cod	GR	Saturates	116.6	Farrington (1972)
Beaufort Sea	Shrimp	GC	n-paraffins	0.37-21.6	Clark (1976)
Southern Beaufort Sea	Plankton (mixed tows)	GC GC	non-polar HC paraffins	1.5-203 0.1-198	Wong et al. (1976)
Southern Beaufort Sea	Arctic cisco	GC GC GC/MS	paraffins non-polar HC PAH	1.3-2.6 2.0-4.0 0.014-0.031	Wong et al. (1976)
Southern Beaufort Sea	Least cisco	GC GC GC/MS	paraffins non-polar HC PAH	1.4-6.0 2.0-7.8 0.019-0.026	Wong et al. (1976)
Southern Beaufort Sea	Pomfret	GC/MS	PAH	0.009	Wong et al. (1976)
Tuk Harbour	Arctic Flounder (muscle) (liver)	 GC GC	 paraffins paraffins	 0.16-4.76 7.5-714	 Thomas (1988)
Tuk Harbour	Starry Flounder (muscle) (liver)	 GC GC	 paraffins paraffins	 0.52-4.4 18.4-227	 Thomas (1988)
Mason Bay	Arctic Flounder (muscle) (liver)	 GC GC	 paraffins paraffins	 0.74-123 71.9-300	 Thomas (1988)
Mason Bay	Starry Flounder (muscle) (liver)	 GC GC	 paraffins paraffins	 0.91-9.7 29.6-224	 Thomas (1988)

* GC = Gas chromatography
GC/MS = Gas chromatography/mass spectrometry
GR = gravimetric

Table 5. The hydrocarbon content of Arctic marine sediments.

Location	Depth*	Number of samples	Method of analysis **	Type of hydrocarbon	Hydrocarbon content***	Reference
USA-Canada						
Hutchinson Bay			GC	n-alkanes	7.8±5.2 µg/g wet	Thomas (1988)
			GC/MS	PAH	480±360 ng/g wet	
McKinley Bay			GC	n-alkanes	8.3±7.8 µg/g wet	Thomas (1988)
			GC/MS	PAH	260±290 ng/g wet	
Tuktoyaktuk Harbour			GC	n-alkanes	17.5±6.6 µg/g wet	Thomas et al. (1983)
			GC/MS	PAH	960±730 ng/g wet	
Tuktoyaktuk Harbour			GC	n-alkanes	12.2±5.4 µg/g wet	Thomas et al. (1983)
			GC/MS	PAH	1050±620 ng/g wet	
Kugyuktuk Bay			GC	n-alkanes	5.1±0.6 µg/g wet	Thomas et al. (1983)
			GC/MS	PAH	380±40 ng/g wet	
Beaufort Sea	2-11/0	20	GC	Saturates	0.1-12.5 µg/g	Shaw et al. (1979)
Pruhoe Bay	-/0	18		Extractable HC	1.8-43 µg/g wet	Shaw and Cheek (1976)
Southern Beaufort Sea (Canada, 1974)	7-191/0	14		Parrafins	2.6-18.0 µg/g	Wong et al. (1976)
				total HC	18.4-164 µg/g	
Southern Beaufort Sea (Canada, 1975)	14-155/0	15		Parrafins	6.0-23.6 µg/g	Wong et al. (1976)
				total HC	36.9-109 µg/g	
				PAH	120-2890 ng/g	
Greenland						
63°-68°N off West Coast			GC	total HC	0.06-0.610 µg/g	Jensen et al. (1977)
Norway						
Tromsøflaket	?/0-1		GR	total HC	3.4±3.6 µg/g	Aamot (1990)

* Given as water depth (m)/sample depth (cm)

** GC = Gas chromatography
GC/MS = Gas chromatography/mass spectrometry
GR = gravimetric

*** Hydrocarbon (µg)/dry sediment (g), unless otherwise specified.

Table 6. Year to year variations (Melnikov et al., 1990)

a) USSR (winter-spring) - year to year variation of total petroleum hydrocarbons in surface waters (μg/l).

Year Location	1982	83	84	85	86	87	88	89	Mean	Mean dev.
Kara	48.0	37.5	40.0	31.0	32.0	36.0	≤30.0	30.9	35.7	6.2
Laptev	50.0	37.3	33.3	≤30.0	36.0	37.0	≤30.0	33.0	35.9	6.4
East Siberian	43.0	32.0	59.3	31.4	38.0	47.0	≤30.0	≤30.0	38.0	10.5
Chuckchi	46.0	≤30.0	47.6	30.5	31.4	48.0	33.0	≤30.0	36.9	8.6

b) USSR (summer-spring) - year to year variation of total petroleum hydrocarbons in surface waters (μg/l).

Year Location	1982	83	84	85	86	87	88	89	Mean	Mean dev.
Kara	-	-	-	38.8	36.0	25.0	≤30.0	38.0	33.6	5.9
Laptev	34.4	≤30.0	≤30.0	35.0	≤30.0	-	-	-	32.3	2.6
East Siberian	-	-	-	-	-	-	-	-	--	
Chuckchi	31.3	33.1	33.1	≤30.0	-	-	≤30.0	≤30.0	31.5	1.6

c) USSR (summer-fall) - year to year variation of total petroleum hydrocarbons in snow on Arctic seas (μg/l).

Year Location	1986	87	88	89	Mean	Mean dev.
Kara	≤30.0	≤30.0	≤30.0	37.9	30.4	2.2
Laptev	32.5	≤30.0	30.5	33.7	30.8	1.2
East Siberian	54.0	53.0	45.4	45.8	45.6	11.1
Chuckchi	43.3	37.0	44.0	40.0	43.8	5.4

Environment. A list of recommendations will be presented and discussed on the Ministerial Conference in Rovaniemi, Finland, June 1991. One of the recommendations is to establish an Arctic Monitoring and Assessment Program (AMAP). The objectives of this program is to co-ordinate the monitoring performed by the participating countries in order to define the sources, pathways, sinks and effects of all kind of pollution on the Arctic (marine, freshwater, terrestrial, and atmosphere) environment. Based on the monitoring results status reports on the Arctic environment are planned to be presented at fixed intervals.

Other actions discussed are to implement the strictest international standards regarding discharges of oil from all sources taking into consideration existing agreements and conventions (e.g. the International Maritime Organization, IMO).

The discussions will also include actions on prevention of accidental pollution, as cooperation on standards, technologies and principles.

The development of an effective emergency response system is also important. Several elements of importance in this respect will be discussed in Rovaniemi including the establishment of an early notification system, cooperation in development of methods and technologies for preparedness and response to accidental oil pollution, assessments of risks for accidental pollution in association with different activities, etc.

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THE MARINE TRANSPORT OF OIL AND OTHER NOXIOUS SUBSTANCES IN CANADIAN COAST GUARD CENTRAL REGION 1987-1989

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Central Region
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INTRODUCTION

Background

The Canadian Coast Guard has the prime responsibility to ensure that appropriate reporting, surveillance and response capabilities are available to deal effectively with an accidental or intentional discharge of oil or other noxious substances. This responsibility is exercised through the National Marine Emergency Plan, the Canada Shipping Act, the Arctic Waters Pollution Prevention Act and under the Great Lakes Water Quality Agreement.

The International Maritime Dangerous Goods Code (IMDG Code) provides international requirements for the vessel transport of hazardous materials. Canadian and foreign-registered ships, as well as those carrying domestic consignments of dangerous goods, must adhere to regulations outlined in the Transport of Dangerous Goods Act and the Canada Shipping Act while in Canadian waters.

Despite the requirements and regulations which are in place to aid the prevention of problems, spills continue to occur. Over the past few years there have been a number of major oil spills worldwide: 1 off the coast of Washington State on the 23rd of December, 1988, 1 in Prince William Sound, Alaska and 1 off of the east coast of Newfoundland on the 24th of March, 1989. In Central Region the most significant incident occurred in the St. Lawrence River on June 23, 1976 when the barge NEPCO 140 grounded off the shores of New York State. The most recent of spills that the Emergency Operations Branch in Central Region has responded to was a spill of 250 tons of tallow from a tanker at Clarkson harbour on April 26, 1989. At the end of the calender year 1990, there had been a total of 185 pollution spills reported in Central Region.

In order to respond to the concerns expressed regarding spills, it is necessary to develop knowledge of the products and the volumes which are being shipped. Such is being done on an annual basis by Central Region's Emergency Operations Branch who have a mandate to deal with pollution spills at the prevention and response levels. As part of the Coast Guard's responsibilities, contingency plans for the response to pollution spills are continually reviewed and updated. Through field investigations and analysis of shipping patterns, the result are that areas of concerned and identified and changes to the Coast Guard's response capabilities.

Under regulations defined by Revenue Canada Customs and Excise, all vessels moving in and out of Canada must provide cargo and vessel declarations for cargo and vessel declarations for each shipment. Port of origin and destination, cargo descriptions, tonnage, vessel name and call sign are included in these declarations. Vessels travelling solely within Canada must adhere to similar rules also outlined by Revenue Canada. Cargo and vessel information is supplied by each ship on a mandatory basis. Existing SLSA regulations require that vessels declare their cargo when entering a lock system.

The Coast Guard has identified the different areas in Canada into 6 regions. Central Region is defined as the area from the Beauharnois Canal, Quebec; through Ontario to Churchill and Lake Winnipeg, Manitoba, **Figure 1 (insert regions map).**

Purpose

This document is intended to aid the contingency planning for emergency situations within Central Region. Research has been conducted in order to gain information about the movement of hazardous materials in the Great Lakes/St. Lawrence River system.

Although the existing mandate includes hazardous materials, the Emergency Operations Branch response capabilities are currently restricted primarily to oil spills. This study has been initiated to acquire information about petroleum products (hereinafter referred to as products of interest) and floating chemicals in preparation for a revised minimum level of CCG response to marine emergency incidents in Central Region.

METHOD

For the purposes of this paper, the CCG Central Region is concerned with products which meet specific criteria as outlined above.

This study not only focuses on Canadian waters in Central Region but also on the U.S. portion of the Great Lakes due to the fact that ships bound for American ports often cross into Canadian waters and pollution seldom respects international borders. It is therefore necessary to look at the movement of products of interest in the entire waterway system.

Although the initial intention of this study was dependent on information collected from chemical and petroleum companies, it was found that government agencies collecting statistical data provided a stable and reliable source of information. This paper uses this data to show a holistic view of shipments of products of interest in the Great Lakes.

DOMESTIC AND INTERNATIONAL SHIPPING IN THE GREAT LAKES REGION

Domestic Movement of Commodities in the Great Lakes

Domestic shipments of products of interest in the Great Lakes were analyzed, separating Canadian and U.S. domestic shipments: Canadian domestic shipments for the years of 1987 - 1989, listed by waterbody and by commodity and U.S. Great Lakes domestic shipments were analyzed by product for 1987 and 1988.

Figure 2 illustrates the shipments to and from Central Region ports listed by waterbody. This chart shows clearly a change in shipping patterns between the lakes. In 1987 the highest amount of domestic traffic occurred in the Detroit River/St. Clair River area. This would be explained by the location of the Petroleum and Chemical refineries located along this waterbody. Lake Ontario recorded the

Figure 1

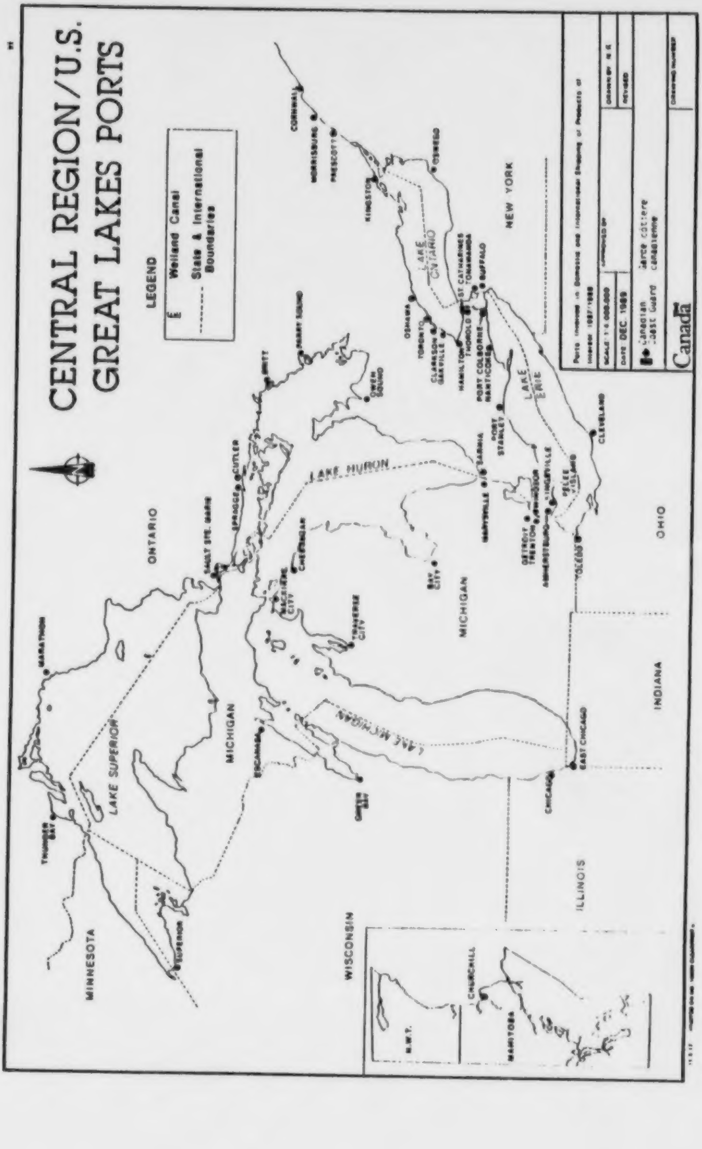
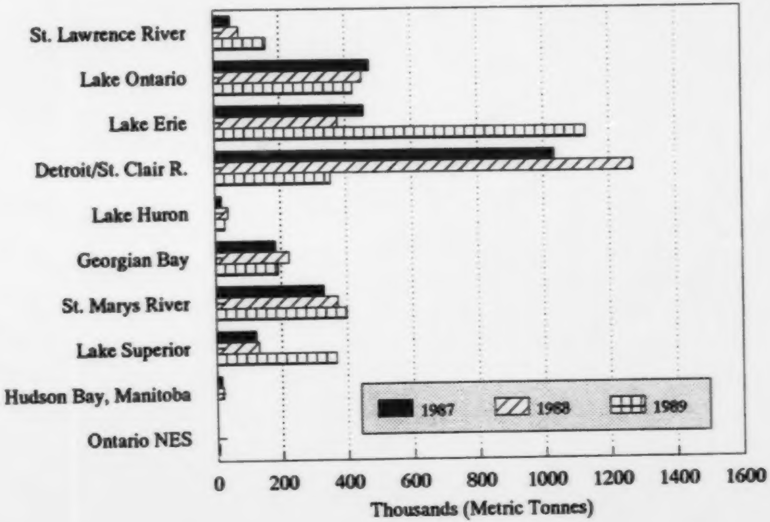

CENTRAL REGION/U.S. GREAT LAKES PORTS
LEGEND
E Welland Canal
State & International Boundaries
MINNESOTA
WISCONSIN
ONTARIO
MICHIGAN
ILLINOIS
INDIANA
OHIO
NEW YORK
LAKE SUPERIOR
LAKE MICHIGAN
LAKE HURON
LAKE ERIE
LAKE ONTARIO
THUNDER BAY
MARATHON
SUPERIOR
SAULT STE. MARIE
SPRAGGE
CUTLER
BRITT
PARRY SOUND
OWEN SOUND
SARNIA
PORT STANLEY
PORT COLBORNE
NANTICOKE
HAMILTON
CLARKSON
OAKVILLE
TORONTO
OSHAWA
ST CATHARINES
THOROLD
TONAWANDA
BUFFALO
KINGSTON
PRESCOTT
MORRISBURG
CORNWALL
OSWEGO
MARYSVILLE
DETROIT
TRENTON
WINDSOR
AMHERSTBURG
KINGSVILLE
PELEE ISLAND
TOLEDO
CLEVELAND
BAY CITY
CHEBOYGAN
MACKINAW CITY
TRAVERSE CITY
ESCANABA
GREEN BAY
CHICAGO
EAST CHICAGO
N.W.T.
MANITOBA
CHURCHILL
FIGURE 1
Ports Involved in Domestic and International Shipping of Products of Interest 1987/1988
SCALE 1:4 000 000
DATE DEC. 1989
Canadian Coast Guard
Garde côtière canadienne
Canada

Figure 2

PRODUCTS OF INTEREST SHIPPED TO & FROM CENTRAL REGION PORTS, 1987-1989



second highest amount of shipping followed by Lake Erie. The same pattern appeared in 1988 with the traffic in the Detroit River/St. Clair River increasing dramatically. However, in 1989 shipping patterns changed and volumes shipped in Lake Erie increased, and this area had the highest volume of products of interest transported in the Great Lakes system. Lake Ontario continued to have relatively high volumes shipped, showing a slight fall. The St. Marys River showed a significant increase in volumes being shipped, recording the third highest traffic in the Great Lakes system.

Examining these figures overall, the St. Lawrence River, Lake Erie, St. Marys River and Lake Superior showed an increase in volumes being shipped. Conversely, declines occurred in all other waterbodies. In 1989, no products of interest were shipped in Hudson Bay, Manitoba.

It appears that the changes in shipping do not favour a particular chain of waterbodies, but rather appear to be port/location specific.

This information was also interpreted in **Figure 3** showing specific products shipped in Central Region for the same period of 1987-1989. Over the 3 year period, fuel oil continued to be the commodity shipped domestically in highest quantity is followed by gasoline. Dramatic changes occurred in the shipments of Asphalt, Tar and Pitch and also in Lubricating Oils and Greases which recorded no shipments by 1989. Possible explanations are that modes of transportation have changed or that there may have been a change in reported categories in which these products may have been recorded under Miscellaneous Chemicals. It seems unusual that there would be a dramatic increase in the shipment of Miscellaneous Chemicals due to changes in transportation modes or the increasing demand for these types of products. It does not seem that these products were reported under "Other Petroleum Products" since the shipment of these products appear to have stabilized over the period of 1988 to 1989.

The overall total metric tonnes shipped in Central Region domestically show that in 1987 there were 2.6 million metric tonnes (MT), 1988 recorded a total of 2.9 million MT and by 1989 there were 3.0 million MT shipped. These three years show an steady increase of products of interest shipped domestically in Central Region and would suggest that in this case there has not been any significant decline in the use of waterborne transportation.

The increase in shipments of products of interest was also seen in the U.S. domestic shipments, **Figure 4**. Increases were recorded in all products of interest except for Benzene/Toluene and Lubricating Oils and Greases. Again, this situation raises the possibility of a change in the categories being reported perhaps under reported under Petroleum Products. This could explain Benzene and Toluene not recording any shipments in 1988. In the case of Lubricating Oils and Greases, this decline seems to be industry based since this decline was also recorded at Central Region ports.

Overall figures show that there was a general increase in shipments between 1987 and 1988 from 2.0 million MT to 2.2 million MT. Again, it would appear that waterborne transportation is not declining over the period of 1987 to 1989.

Figure 3

PRODUCTS OF INTEREST SHIPPED IN CENTRAL REGION, 1987-1989

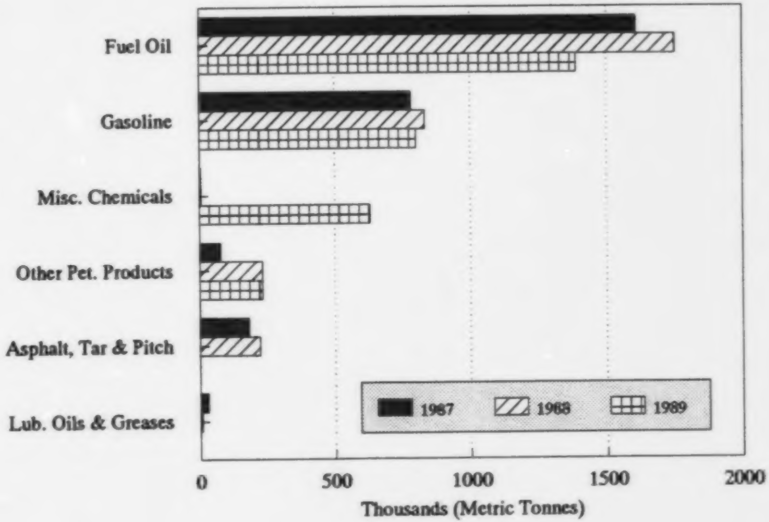
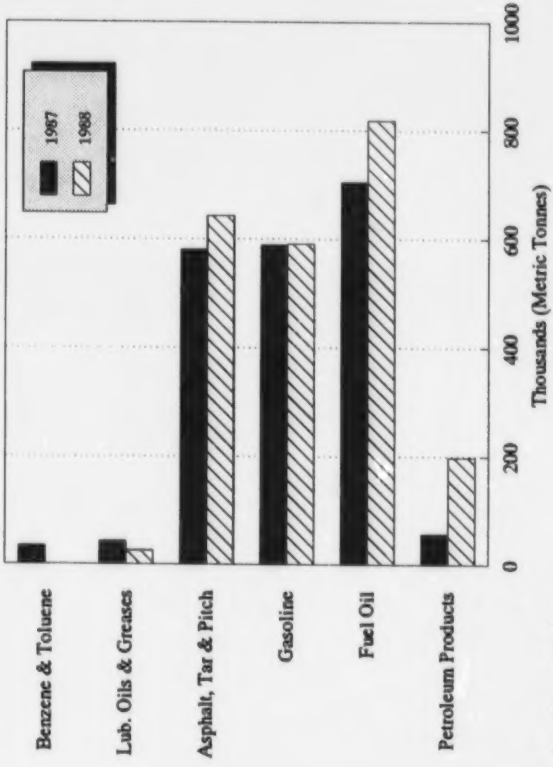


Figure 4

U.S. DOMESTIC SHIPMENTS, 1987/88



Source: U.S. Army Corps of Engineers

International Shipping in the Great Lakes

Besides the domestic movement of products of interest, a considerable volume of products of interest are transported between Central Region ports and other countries. It should be noted that the information presented in the U.S. Great Lakes Overseas shipments does not include those shipments to/from Central Region ports. Conversely, the figures illustrating international shipments do include U.S./Central Region (binational) trading.

Imports & Exports - Central Region

Figure 5 shows products of interest imported to Central Region from overseas ports. Over the three year period of 1987-1989, there has been an increase in imports attributed to a large increase in Fuel Oil and Miscellaneous Chemicals. Decreases were present in only two of the categories: Gasoline and Petroleum and Coal Products. In general there is an increasing trend where imports have gone up from 1.4 million MT in 1987 to 0.9 million MT in 1988 and to 1.4 million MT in 1989.

The opposite is the case in exports, significant declines appearing in Fuel Oil and miscellaneous chemicals, **Figure 6.** The most significant increase occurred in Petroleum and Coal Products. Overall total indicate that exports are declining from 1.4 million MT in 1987 to 0.8 million MT in 1989.

The overall balance of products of interest shipped shows a decline in exports and an increase in imports being shipped into the Great Lakes system.

A quick examination of **Table 1** shows that imports and exports have, over the three year period, becomes limited to fewer waterbodies that are involved in the importing and exporting of products of interest. Between 1987 and 1988 most of the imports are received in ports in Lake Ontario, the Detroit River/St. Clair River and Lake Erie. In 1989 however, ports importing products of interest changes in location to: Detroit River/St. Clair River, Lake Ontario and Lake Huron. It is interesting to note that Lake Erie appeared to have increasing in importing more goods in the first two years but in 1989 imported none at all.

Changes over this specific three year period are not as dramatic in the export of products of interest from Central Region port to other countries. For both 1987 and 1988, the Detroit River/St. Clair River exported the greatest quantity of products of interest in the Great Lakes system. For these years the volumes shipped remained at around a million MT a year but dropped to only 68,000 MT in 1989. This decline is balanced with a steady increase in exports originating from the Lake Ontario area from just under 200,000 MT to over 300,000 MT in 1989. Again, as in the case of imports, the number of areas dealing in international trade has dropped from as many 7 out of 8 waterbodies, to only 3 waterbody areas that export to foreign countries. Only ports in the St. Lawrence River, Lake Ontario, Detroit River/St. Clair River, and Lake Superior export products of interest to foreign (overseas) ports.

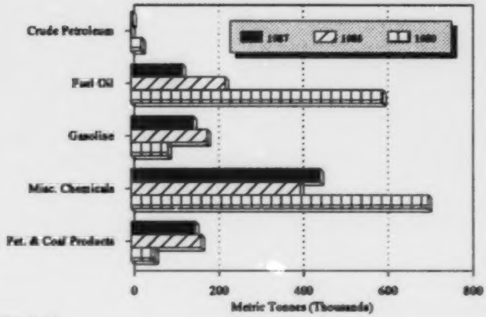
The balance of imports over exports shows that both are declining but Central Region ports export greater volumes of products of interest than they import.

Imports & Exports - U.S. Great Lakes

Besides international traffic involving Central Region ports, products of interest are also shipped to and from American portion of the Great Lakes. **Figure 7 and 8** shows the cargo tonnages imported and exported between U.S. and foreign

Figure 5

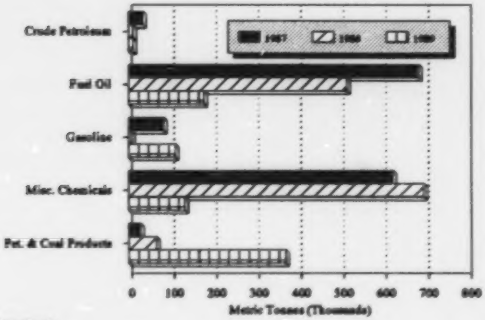
CENTRAL REGION IMPORTS, 1987-1989
By Product



Source: Statistics Canada

Figure 6

CENTRAL REGION EXPORTS, 1987-1989
By Product



Source: Statistics Canada

Table 1

INTERNATIONAL SHIPMENT OF PRODUCTS OF INTEREST WITH CENTRAL REGION PORTS

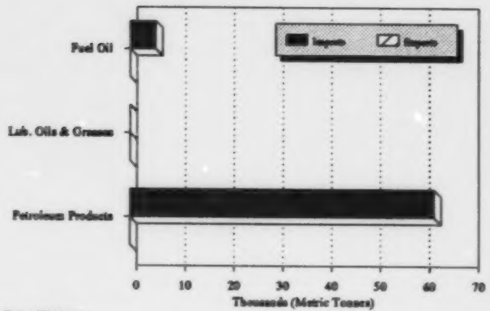
Waterbody	IMPORTS			EXPORTS		
	1987	1988	1989	1987	1988	1989
St. Lawrence River	32,191	19,741	0	0	0	6,147
Lake Ontario	421,489	493,124	22,831	189,059	255,329	328,075
Welland Canal	1,500	0	0	22,553	0	0
Lake Erie	44,375	112,081	0	85,795	43,909	0
Detroit/St. Clair River	341,678	283,378	235,288	1,066,090	901,171	68,645
Lake Huron	0	0	8,000	5,000	42,150	0
Georgian Bay	14,869	39,953	0	0	0	0
St. Marys River	10,886	6,267	0	5,434	11,393	0
Lake Superior	5,893	16,704	0	80,253	40,853	1,505
TOTAL (METRIC TONNES)	872,881	971,248	266,119	1,454,184	1,294,805	404,372

Source: Statistics Canada

Figure 7

U.S. GREAT LAKES, 1987

Overseas Imports & Exports

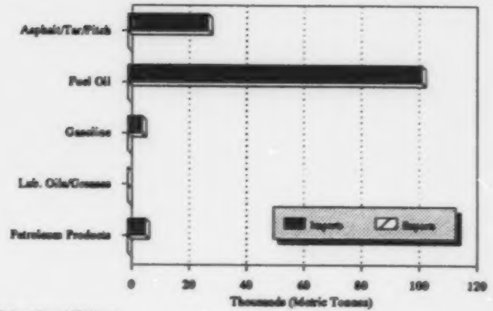


U.S. Army Corps of Engineers

Figure 8

U.S. GREAT LAKES, 1988

Overseas Imports & Exports



Source: U.S. Army Corps of Engineers

port for 1987 and 1988. In both cases U.S. ports are importing more products of interest than they are exporting. One of the major differences between these two years is that there was a dramatic rise in imports of Fuel Oil from 5,271 MT (1987) to 102,325 MT (1988). Also, it appears that the variety of products being imported and exported has increased particularly in the case of Asphalt/Tar/Pitch products. Overall totals show that imports has risen from 67,605 MT (1987) to 141,480 MT (1988). U.S. Exports account for only a fraction of this total tonnage of products transported recording a total of 8 MT (1987) and 5 MT (1988).

It is apparent that Central Region ships a greater volume of products of interest abroad than does U.S. ports and subsequently most of the foreign traffic is originating or is bound for Central Region ports.

Binational Shipping in the Great Lakes

Of the shipments made to foreign ports, a significant quantity of products of interest were transported to U.S. Great Lakes Ports. **Figure 9 & 10** illustrates products being shipped between the U.S. Great Lakes ports and Central Region ports. Examined by product, there was a significant amount of Asphalt, Tar and Pitch being transported to Central Region in 1989 only. This could explain the drops in domestic shipments in both in Central Region and U.S. ports. There is also a significant increase in Benzene and Toluene being shipped to Central Region from the U.S. Declines were recorded in all other products being shipped to Central Region (**Figure 9**) with the most significant drops being recorded in Fuel Oil and Miscellaneous Chemicals.

Overall, between 1987 to 1989 there was a significant decline in products of interest shipped from U.S. port to Central Region ports from 619,309 MT to 268,054 MT.

Many declines area also apparent in shipment from Central Region ports to U.S. ports, **Figure 10**. Most significant declines were observed in Fuel Oil and Miscellaneous Chemicals. Increases occurred in the other products, Asphalt, Tar and Pitch, Benzene and Toluene, and Gasoline.

Overall, there was a fluctuation of shipments causing an increase from 1987 to 1988 (670,896 MT to 1,047,139 MT) and a small decline from 1988 to 1989 (1,047,139 MT to 967,417 MT). This seems to indicate a recovery in the volumes shipped over this three year period.

The combined shipment between Central Region and U.S. Great Lakes ports again shows the fluctuation noted previously, from an increase from 1.2 million MT (1987) to 1.3 million MT (1988) to a decline to 1.2 million MT (1989). As a whole, Central Region ports export more products to U.S. Great Lakes ports than they import.

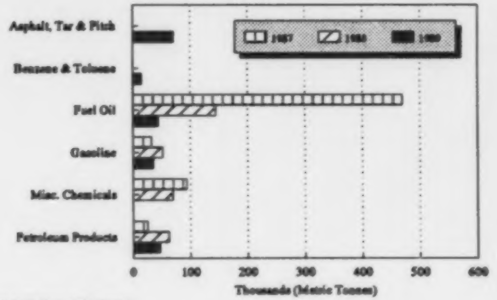
THE ST. LAWRENCE SEAWAY: TRENDS IN SHIPPING

Although the previous sections of this paper focus on specific years that products of interest have been shipped, historical data of shipping patterns have been maintained by the St. Lawrence Seaway Authority, on the passage of vessels through its lock systems in the Montreal/Lake Ontario section and the Welland Canal. The reason that this information is included is that though it concentrates on two particular areas in Central Region, it also provides a good indicator of overall trends. This reference is to the extensive reporting of vessel transits, selected cargo

Figure 9

BINATIONAL SHIPMENTS, 1987-1989

U.S. Great Lakes to Central Region

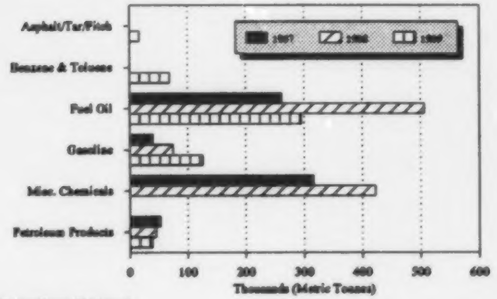


Source: U.S. Army Corps of Engineers &
Statistics Canada

Figure 10

BINATIONAL SHIPMENTS, 1987-1989

Central Region to U.S. Great Lakes



Source: U.S. Army Corps of Engineers &
Statistics Canada

commodities and total cargo tonnes which have been documented from the birth of the Seaway in 1959 until the latest reporting date of 1989. Not only does this information provide an indicator of the volumes of imports and exports, but it also shows the transit of materials within the lake system. Therefore lateral movement (within the system) of products and volumes are shown, as opposed to movement out of the system. It must be stated that though total figures are acceptable for transit of vessels, it poses a problem when considering movement of products since it includes those products which are considered neither hazardous nor of interest to this study. However it gives important overall trends of the usage of waterborne transportation and the volumes of products being transported.

Figure 11 shows the total number of vessel transits through the two sections of the Seaway system, Montreal/Lake Ontario and the Welland Canal, for specific years showing trends throughout the 30 year reporting time period. Peak traffic volumes occurred in 1963 while 1985 is shows the lowest figure. There are higher reported transits through the Lake Ontario/Lake Erie system (Welland Canal) than the Montreal/Lake Ontario section. Trends are mirrored between these two sections the only difference being that transits are higher in the Welland Canal system.

In analyzing vessel transits one must also consider the total cargo tonnage of products passing through the Seaway system. **Figure 12** shows the trends during the same period, 1959 to 1988 again separating the system into two components: the Montreal/Lake Ontario section and the Welland Canal. As was the case in **figure 9**, the Montreal/Lake Ontario section is much lower in cargo tonnages than the Welland Canal. This also confirms the conclusions made previously that there is more domestic than international traffic. This assumption can be made since the Montreal/Lake Ontario section must be traversed if products are able to enter or leave the Great Lakes system. The Welland Canal would be subject to more domestic traffic since this system must be navigated if products are to be shipped to the large populated areas around Lake Ontario, or highly industrialized areas such as the Detroit River/St. Clair River.

Unlike the previous figure, this chart does not clearly show a continuing decline of traffic in the Seaway system. Rather, fluctuations show a trend towards an increase in the total volumes of products shipped in the Seaway. This seems to indicate that cargo capacity of vessels has increased thereby decreasing the number of vessels required in the system making transportation more economical. Currently, the average Great Lakes tanker has been recorded as having an average carrying capacity of 10,000 metric tonnes. No tankers using the system have been built to take advantage of the size of the locks.

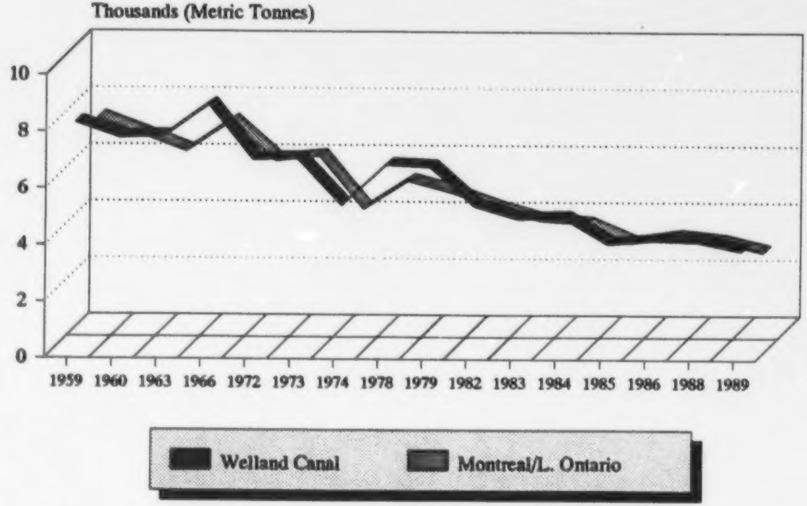
Limited information was available on selected commodities transported through the St. Lawrence Seaway during the 29 year history of the system. **Figure 13** shows the trends for chemicals, fuel oil and gasoline. It must be noted that chemicals includes products which are considered by Transport Canada as being both hazardous and non-hazardous. As such, products which are not of interest to this survey are included. This shows important trends in the transportation of chemicals in general, which otherwise would not have been possible.

The initial volumes of chemicals were low but have steadily increased over the last 3 decades. Trends indicate that the Seaway is becoming more important in transporting chemicals both domestically and internationally.

Recent steady increases have also occurred in the transportation of fuel oil. During the first decade of the Seaway's existence there had been a dramatic increase

Figure 11

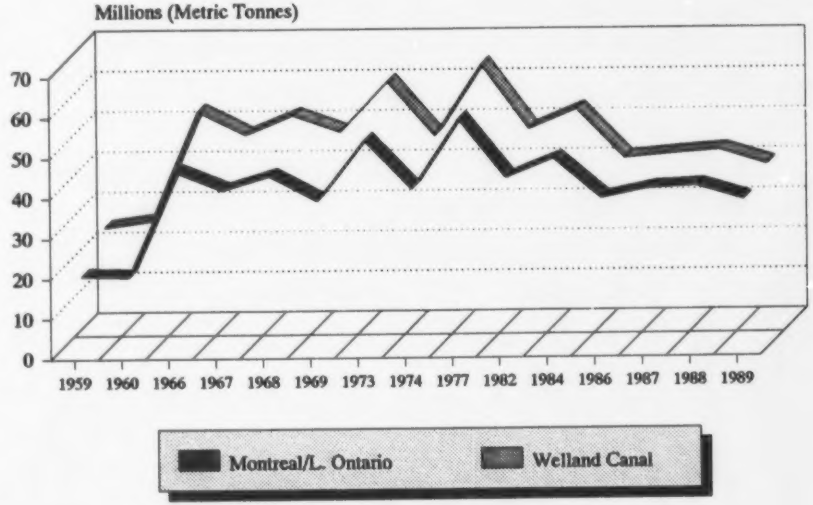
ST. LAWRENCE SEAWAY TRAFFIC
Total Vessels Transits



Source: St. Lawrence Seaway Authority

Figure 12

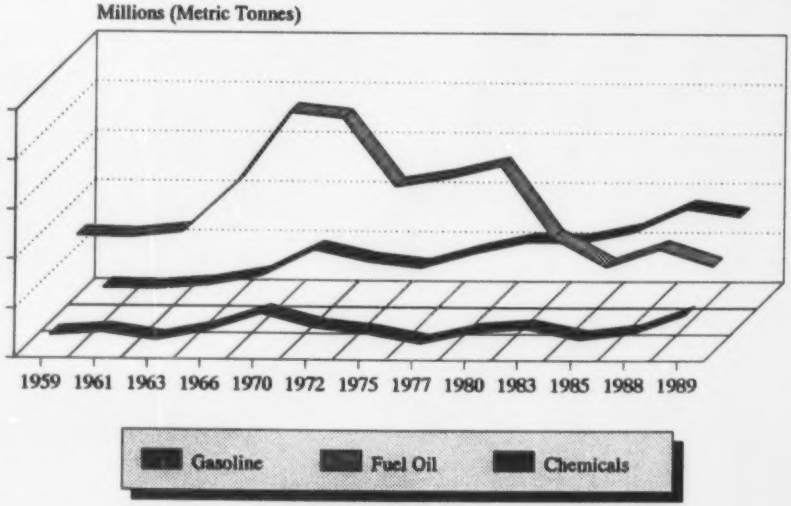
ST. LAWRENCE SEAWAY TRAFFIC
Total Cargo Tonnes Shipped



Source: St. Lawrence Seaway Authority

Figure 13

ST. LAWRENCE SEAWAY TRAFFIC
Selected Commodity Shipments



Source: St. Lawrence Seaway Authority

in cargo tonnages shipped. A sharp decline occurred in the 1970's due to a number of factors including the "oil crisis" in which overseas suppliers controlled the market limiting the movement of oil. This decline continued until 1985 at which point the total volumes began to increase and have continued.

For gasoline the trend over the years has been somewhat of a roller coaster. There have been periods of significant increases in cargo tonnages shipped but, due to changes in the market demand and availability of supplies, declines followed. Overall figures are low due to products being available from domestic (Canadian) suppliers and via other modes of transportation, namely road, rail and pipeline.

Overall shipments of these 3 commodities have begun to increase in the last few years. This cannot yet be established as a long term trend due to the fluctuations which have occurred in the past but it may be a positive indication of a long term trend.

SUMMARY

This report has attempted to describe the activity of the movement of products of interest in Central Region and in the Great Lakes/St. Lawrence as a whole. The previous pages and charts have shown information regarding the transportation of products of interest, movement of these products at Central Region ports, imports and exports with other countries and the movement of products in the U.S. portion of the Great Lakes. Together this information has been assembled in the following Table and Figures to provide an overall view of what is entering or leaving the Great Lakes/St. Lawrence River region.

Table 2 gathers information of domestic movement, imports and exports to and from Central Region ports for both 1987 and 1988. In summary, there are a number of ports in Central Region which play major roles in the transportation of products of interest in the Great Lakes/St. Lawrence River. There are sudden changes in the products of interest being transported in this Region. Most prevalent were the changes to the Detroit River/St. Clair River area from the two year period of 1987/88 and its subsequent decline to a fraction of the total volume shipped. It appears that Lake Erie has grown in importance, as a leading originator and receiver of products of interest in the Great Lakes, shifting the emphasis away from the Sarnia/Chemical valley of the Detroit River/St. Clair River.

Although there is a shift in the areas trading products of interest, Lake Ontario remains as one of the sections that is still important to shipping.

Ports growing in importance to the shipping industry are located in the St. Lawrence River, the St. Marys River and Lake Superior. Conversely, declines are occurring in the Georgian Bay/Lake Huron portion of the Great Lakes. Compared to other areas in Central Region, Georgian Bay/Lake Huron does not have as many heavily concentrated chemical/petroleum industries as compared to the eastern portion of the Lakes.

In terms of the entire picture, the following three charts illustrates the total shipments in the Great Lakes/St. Lawrence River. This chart describes the total movement in the Great Lakes/St. Lawrence River by combining all different types of shipping: domestic and international shipping in both Central Region and the U.S. Great Lakes. The pie graph (**Figure 13**) shows the following percentages for 1987:

Table 2

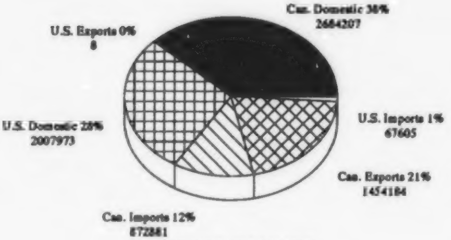
DOMESTIC AND INTERNATIONAL SHIPMENTS OF PRODUCTS OF INTEREST HANDLED BY CENTRAL REGION PORTS, 1987 - 1989

Waterbody	YEAR 1987	1988	1989
St. Lawrence River	84,286	98,134	165,614
Lake Ontario	1,083,003	1,198,821	773,437
Lake Erie	585,656	531,129	1,128,770
Detroit/St. Clair River	2,441,237	2,455,548	656,557
Lake Huron	25,114	82,776	38,412
Georgian Bay	198,860	264,309	190,205
St. Marys River	345,099	389,400	395,896
Lake Superior	207,227	188,009	367,381
Ontario NES	24,053	1,217	5,035
Hudson Bay, Manitoba	16,742	20,395	0
TOTAL (METRIC TONNES)	5,011,277	5,229,738	3,721,307

SOURCE: STATISTICAL AGENCIES

Figure 14

PRODUCTS OF INTEREST SHIPPED, 1987
Central Region/Great Lakes

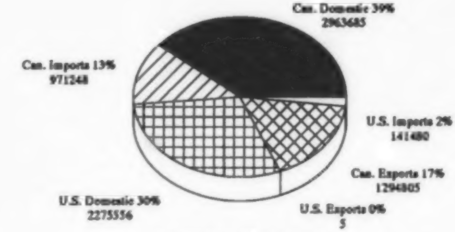


METRIC TONNES

Source: Statistical Agencies

Figure 15

PRODUCTS OF INTEREST SHIPPED, 1988
Central Region/Great Lakes



METRIC TONNES

Source: Statistical Agencies

38% - Central Region domestic
28% - U.S. domestic
21% - Central Region exports
12% - Central Region imports
1% - U.S. Imports
0% - U.S. exports

In 1988, the largest source of shipping in the Great Lakes/St. Lawrence River system was again domestic shipping (Figure 14). The following percentages applied:

39% - Central Region domestic
30% - U.S. domestic
17% - Central Region exports
13% - Central Region imports
2% - U.S. imports
0% - U.S. exports

Data available for 1989 reflects movements in Central Region only (**Figure 15**):

Overall the data presented seems to indicate that marine transportation of products of interest is increasing in volumes shipped. Fuel oil is the commodity transported in Central Region and in the U.S. Great Lakes in greatest quantity, occurring in both international and binational trading. The binational trade with the U.S. shows how significant the U.S. is to Canada as a trading partner.

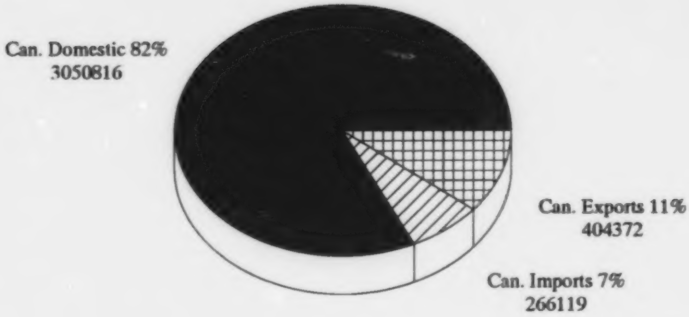
Having analyzed data for both domestic and international movement, it is clear that the differences may be explained by changes in the sources of products from domestic to foreign sources. Such appeared to be the case in the decline in products such as Asphalt, Tar and Pitch and Benzene and Toluene can be attributed to changes in origin of products away from domestic to binational shipments.

Further generalizations can be made such as increases in domestic trade in both Central Region and the U.S.. Such increases also occurred in U.S. imports while U.S. exports declined. Central Region foreign trading did not have identical trends, rather both imports and exports have declined (this includes binational shipments).

This information is important as an indicator of the kinds of hazardous materials shipped and volumes and types of movements in Central Region. This report provides primary information which is currently not available elsewhere. By combining data from a variety of sources, the result is a package that is a necessary component of contingency planning. As previously stated, there have been a number of spills in the past, which have repeatedly brought up the question of what is being transported in Central Region. It was not until this study was initiated in 1986 that there was an attempt to establish estimates of the cargo tonnages shipped. This report hopefully sheds more light on the issue of the transportation of hazardous materials, and becomes a tool in planning for the response to spills of oil and hazardous materials, as well as a reference document for information that is found in no other single source.

Figure 16

PRODUCTS OF INTEREST SHIPPED, 1989
Central Region/Great Lakes



METRIC TONNES

Source: Statistical Agencies

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Various Canadian and American chemical companies
Canadian Centre for Occupational Health and Safety

PROBABILISTIC FORECASTING OF LIQUID CARGO SPILLS IN PORTS

by

Terence D. Smyth and Anthony C. Purdon

Sandwell Inc.

INTRODUCTION

The Vancouver Tanker Risk Analysis Project

In 1990, Vancouver Port Corporation (VPC) retained Sandwell Inc., in association with Seaconsult Marine Research and Bennett Environmental Consultants as sub-consultants, to assess the risk of tanker traffic movements within the Port of Vancouver. The objective of the study was to determine the environmental, human safety and operational risks of the movement of crude oil, petroleum products and liquid chemicals by tanker and tanker barge within Vancouver Harbour.

The overall study scope included:

1. A profile of the bulk liquids terminals in Vancouver Harbour, including commodity volumes, vessel types, suitability of docking facilities, accident rates, spill consequences and training standards.
2. A review of the current regulatory framework for the movement of tankers within the port.
3. Definition of current operating procedures for arrival, loading and departure within the port.
4. A quantitative risk assessment which included:
    - Estimates of the probabilities of accidents and spills, and spill size distributions in the harbour.
    - An assessment of the physical, biological and human exposure environments of the port.
    - Development of a number of critical accident and spill scenarios.
    - Prediction of the fate of the spills (including evaporation, biodegradation, spreading, forming of emulsions, dissolution, dispersion, and entrainment).
    - The impact of the spills on the harbour environment.
    - An evaluation of the change in risk for increased traffic movements.
5. Assessment of the protective and contingency measures required to respond to the predicted spills and comparison of these requirements to existing measures.

6. Recommendations on areas in which existing environmental response capabilities may be improved.

The focus of this paper is on a narrow topic within the overall study for VPC: the first point of Item 4. above - the estimates of the probability of liquid cargo spills.

The VPC study is in the final editing stages. Because VPC has not yet released the study to the public, it would be inappropriate for Sandwell to present the results for Vancouver Harbour. Nevertheless, VPC has kindly agreed to allow Sandwell to incorporate some of the work of the study into this paper. The focus of the paper is on the study's approach to probabilistic forecasting of liquid cargo spills and the data the study used.

The probabilistic forecasting component of the study for VPC involved:

- Developing an overall model for the estimates of tanker casualties.
- Reviewing and selecting data sources for vessel casualties.
- Collecting and compiling the data.
- Adjusting the casualty data for Vancouver Harbour.
- Developing results for Vancouver.

This paper concentrates of the on the first three items above. Although it mentions briefly the adjustment of casualty data for Vancouver, it stops short of presenting spill probabilities for Vancouver Harbour. To give some meaning to the quantitative results of Sandwell's work in the absence of specific discussions of Vancouver, the paper extends the results to a hypothetical crude oil port and compares them with casualty estimates from another source.

Definitions

The paper uses several terms which need definition. These are:

Nature of Cargo Spills:

- Operational spills arise from human error or equipment failure during the transfer of bulk liquids from a vessel to a shore terminal or the reverse. Such spills also result from transfers of fuel oil from bunkering barges to ships. Operational spills which may originate from equipment failure or human error, but result subsequently in explosion and fire are categorized as serious casualties; these are not included as operational spills.
- Minor casualties are defined as those collisions, groundings, strikings, fires, explosions and structural failures which result in a loss of liquid cargo of less than 159 cubic metres (1,000 barrels).
- Major casualties are those which result in a spill of cargo greater than 159 cubic metres (1,000 barrels).

Kinds of Casualties:

- Collision: impact between two or more vessels underway.
- Grounding: impact and or stranding of the vessel on the seabed.
- Striking: impact with a stationary object (bridge abutment, berth as two examples) or a vessel not underway (at anchor, or at berth).
- Fire/Explosion
- Structural Failure: global or local failure of the hull or tank structures.

APPROACHES TO TANKER RISK ASSESSMENT

This section draws together the theoretical and practical considerations applicable to tanker risk analysis. It concludes with a summary of the implications of these for the model chosen for the VPC study.

All studies of vessel casualties encounter two fundamental problems:

- vessel casualties and tanker spills are such rare events that casualty statistics for any one port are generally too limited to provide a reliable and valid estimate of future casualty rates, and
- data from other ports are not directly transferable to the port under study because the ports differ in physical characteristics, operational rules and traffic.

This work in the study had to recognize these problems in the overall approach taken to develop estimates of casualty rates.

Theoretical Models

Three broad categories of tanker risk models are relevant to this study: deterministic models which relate physical phenomena to each other according to basic rules of physics and mathematics or empirically observed relationships; probabilistic models, developed from probability theory and work in other risk analysis fields, which capture the uncertain characteristics of the physical phenomena of relevance to tanker risk assessment; and the reliability models which are a special case of probabilistic models.

Deterministic Models

The main kinds of deterministic models which may be of relevance to tanker risk assessments are:

- equations of motion for vessels underway;
- navigation models used by navigation planners to predict vessel behaviour;
- equations that relate the structural response of vessels to impacts that transfer energy from one colliding vessel to another;

- the relationship between the rupture of cargo tanks, and the design of the vessel and the nature of the impact.

Probabilistic Models

The probabilistic models (or probability distributions) that are of relevance to this study are those that have a theoretical or empirical justification for tanker risk analysis. Such models are useful to develop conceptual understandings of the processes that create accidents and to translate observed data from one set of conditions to another. This section discusses briefly the models that have proven useful in past tanker risk analyses.

Research has shown that direct prediction of cargo losses is inappropriate because the volume of liquid cargo lost for a tanker port varies greatly from year to year. The number of cargo spills under given conditions, however, has generally proven to be predictable as has the distribution of spill sizes. The overall probabilistic approach to tanker casualties therefore divides into three related components:

- the probability of a tanker casualty of any kind;
- the probability of a cargo spill given a tanker casualty;
- the probability distribution of the amount of cargo lost.

Casualty Models

Because cargo spills are a subset of all tanker casualties, one can consider models for both at the same time. The following paragraphs discuss models for tanker casualties, but they apply equally to cargo spills.

As with all casualty processes, tanker casualties are expressed as a rate over some exposure variable such as number of tanker accidents per 10,000 port calls or million cubic metres of cargo transported. Both theoretical considerations and practical applications involving vessel and other kinds of casualties lead to the Poisson model for such processes. The formula for the Poisson model is:

$$P(n) = \frac{(\lambda t)^n e^{-\lambda t}}{n!}$$

in which:

- "n" is the number of tanker casualties (or alternatively the number of spills);
- "t" is the exposure variable (such as number of port calls); and
- λ (lambda) is the mean casualty rate expressed in units that are consistent with the exposure variable (such as tanker accidents per 10,000 port calls).

The assumptions behind the Poisson model include:

- The underlying process causing the casualties is constant, and λ does not change with different levels of the exposure variable.
- The underlying process generates casualties independently - the occurrence of one casualty does not affect the probability of another.

- The probability of occurrence of a casualty is proportional to the amount of exposure to the exposure variable.

These assumptions have proven broadly reasonable for vessel casualties. Various researchers have used this model in their work and in many cases have demonstrated that the model fits the observed data quite well. The independence criterion probably does break down on occasion; following major tanker casualties, vessel operators are often under close scrutiny for some time and accordingly take greater precautions, and in the long term the casualty may result in changes in operating regulations that reduce the casualty rate.

Estimating λ is relatively straight forward if a large amount of data is available. If one observes "v" casualties in "τ" exposures, the mean casualty rate is:

$$\lambda = v/\tau.$$

If the sample size is more limited, the casualty rate can be considered a random variable described by a probability distribution with parameters determined by the observed casualties and amount of exposure. The natural distribution for λ is a "gamma" and combining the Poisson and gamma distributions results in a negative binomial distribution of the form:

$$P(n \mid v,\tau,t) = \frac{\left(\frac{t}{T}\right)^{n} \qquad (n+v)!}{[1+t/T)]^{(n+v+1)} \qquad n!v!}$$

The derivation for this form of the negative binomial distribution may be found in texts dealing with Bayesian methodology.

Although the negative binomial may be used as a substitute for the Poisson, a simpler result is that in the case of small data samples one can estimate the mean casualty rate as

$$\lambda = (v+1)/\tau$$

and use the result in a Poisson model. The standard deviation on the casualty rate is:

$$(v+1)^{0.5}/\tau$$

In other words, recognizing λ as a random variable and accounting for the limited data that invariably is available for a tanker risk analysis leads to a more conservative estimate than if the process were considered to be a simple Poisson. The mean casualty rate approaches v/τ as the exposure and number of casualties become larger.

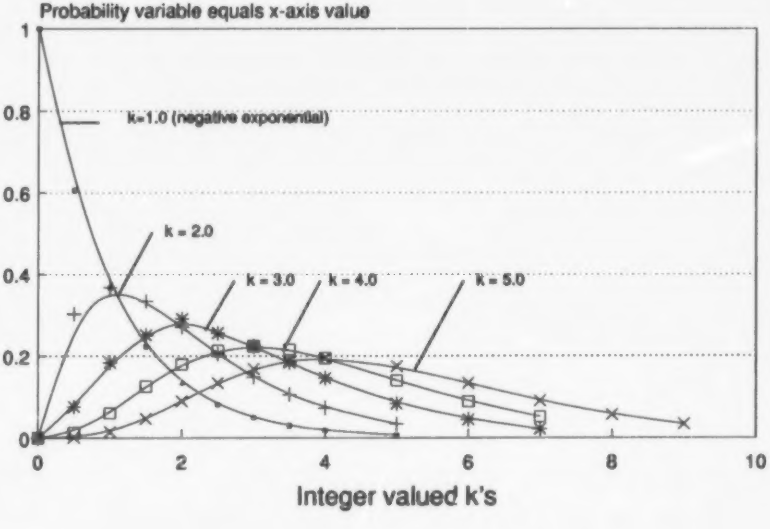
The Poisson model has several useful features. Among these is that casualty rates (λ) that form subsets of others are additive to create an overall casualty rate. For example, if one has three separate casualty rates for collisions, groundings and strikings, the overall casualty rate for these three kinds of accidents is the sum of the three rates. Alternatively, an overall casualty rate can be separated into its components through probability calculations.

Spill Sizes

Unlike the Poisson model for casualties, there is no strong theoretical basis for the choice of a spill size model. Perusals of spill data indicate that the model must account for both a relatively large number of small spills and infrequent large ones; the probability distribution must be highly skewed. Various researchers have used the exponential, lognormal and gamma distributions for spill sizes, and have obtained reasonable compliance with their data. The gamma in particular is a flexible distribution whose shape is controlled by one of its parameters; its extremes range from an exponential distribution skewed against the origin to a highly symmetric distribution (see Figure 1).

In the end, the choice of a spill size distribution will is empirical. Although the distribution must have reasonable properties for the purpose (such as the gamma and lognormal above), the distribution must fit the data well.

Figure 1 - Gamma Distributions
Range of Curve Shapes



Probability Calculations

In general, probabilistic modelling of complex processes such as tanker cargo spills involves combining several random variables to calculate a result. The mathematics of probability distributions makes the analytical combination of distributions all but impossible in most practical cases. One particular case in which the mathematics is tractable is the aggregation and dis-aggregation of lambdas (λ) described above.

A more general approach to solving functions of several random variables is to represent probability as discrete distributions and to use a probability tree to calculate the combinations of outcomes and their probabilities. The probability tree also allows easy representation of conditional relationships: probability distributions whose values depend on other variables.

Reliability Models

Reliability models are detailed, logical networks that build up the events that can lead to a catastrophe or other final event. Sometimes called fault trees, these models require the study team to conceive the logical links that lead to a casualty before they can be captured in the model. A general probability model such as the Poisson process, on the other hand, captures all possible outcomes and processes if its data set is sufficiently comprehensive. The general probability approach, however, provides little information about the structure of the accident causes.

The reliability approach has two fundamental problems:

- It requires data on a wide variety of events that can lead to a casualty. In most cases, this data is not available or must be transposed from other areas or fields.

- The comprehensiveness of the model depends entirely on the ability of the researchers to conceptualize all possible events that can lead to a casualty. Experimentation has shown that even experts in narrow fields tend to leave out many of the events that should go into models concerning their specialties.

The main power of reliability models is their ability to predict the relative risk of alternative designs or courses of action. The models can be most valuable in minimizing the risk of new kinds of processes or plants.

Practical Approaches Taken by Others

Although a narrow field, tanker risk analysis has attracted a considerable amount of effort over the last 20 years and in particular following the breakup of the Torrey Canyon off the coast of England in 1967 - the first major oil spill from a "supertanker." Much of the early work concerned crude oil transport from Alaska, and in general the focus has been on crude oil.

The approaches taken by the researchers fall into two main categories:

1. Drawing inferences about the area from which the data originated.

   Such approaches avoid the problem of translating data from one area to another, but are of course limited in scope because of this. The statements that flow from such work are valid only for the area under study. Examples from past studies include:

   - Using a negative binomial distribution (the transform of the Poisson distribution as above) in conjunction with world data to predict the inter-arrival times between major oil tanker casualties.

   - Developing casualty rates by waterway section in the Port of Rotterdam to assess the risk by area of LPG, chlorine and ammonia transport. This port is one of the few in the world with sufficient traffic to generate reliable casualty statistics; it handles over 100 million tonnes a year of liquid bulk cargoes.

- Collecting essentially complete information on larger world crude oil spills and using a negative binomial distribution to draw inferences about the risk of tanker casualties at sea and in port, and spills and certain sizes of spills.

2. Drawing inferences about a particular area by using data from other sources.

   This is the most common case for most ports around the world. Approaches taken by others include:

   - Direct use of world or particular data without adjustment to draw inferences about particular ports or navigation areas. One study used data from several U.S. ports to develop casualty rates for Puget Sound. Another group routinely uses casualty data for world crude oil tankers to predict oil spills in U.S. waters. The assumption in such an approach is that there is no difference between the area under study and the area from which the data originated.

   - Creating an index of relative tanker risk and using the index to translate casualty data from broader areas to particular ports or waterways. Two Canadian studies have taken this approach by developing subjective indexes from the opinions of several experts.

   - Using casualty data from another part of the world combined with simple deterministic modelling and the expertise of the maritime professionals conducting the study to modify the data for local conditions. A study of the risk of bulk carrier movements in Hong Kong took this approach.

   - Splitting the casualty events into sufficient detail to make valid the direct translation of casualty data from one area to another. Fault tree analysis is such an approach. One study that used fault trees to evaluate alternative tanker designs and operating conditions showed that careful specification could create a tanker that is 100 times less likely to spill cargo than conventional tankers.

Implications for the Vancouver Study

The concepts of tanker risk analysis and the work conducted by others had several implications for the study for VPC:

1. The study should take a broad probabilistic approach to the risk of tanker spills. It should also draw on deterministic models whenever these add to the understanding of a problem.

2. The Poisson process is the most valid probability model for the incidence rate of tanker casualties and spills. In practice, the negative binomial transform or the resulting formula for the mean casualty rate should be used to calculate casualty rates because of the small numbers of tanker casualties.

3. The spill size distribution will have to be chosen empirically. The two likely candidates are the gamma and lognormal.

4. The past studies have shown that a port with limited traffic (and hence exposures) will not generate valid casualty statistics. Compiling and translating data from other areas will be necessary.

5. No one way of translating data from one port to another is both theoretically valid and practical. As in past studies, an opportunistic approach will be necessary.

6. Tanker designs or operating rules have the potential to substantially reduce the risk of casualties. By implication, a port operating under strict rules could have, at least in theory, much lower casualty rates than the world in general.

7. Much of the previous work has focused on crude oil tankers, while the VPC study covers all types of tanker ships and barges, and the commodities include all liquid bulks (crude oil, petroleum products, and liquid chemicals).

THE TANKER CASUALTY MODEL

The tanker model developed for the VPC study was defined by its overall structure, driving variables, calculation methods and data analysis.

Model Structure

The structure of the overall model followed from the considerations summarized above. Figure 2 shows the modelling process that Sandwell applied to the VPC study. Although the overall model is discussed below, the quantitative results exclude those for Vancouver Harbour. The shaded areas of Figure 2 indicate those covered by the paper.

Separate models were developed for each major group of vessels. For vessel classes that carry a variety of commodities, commodity type is also a variable.

The fundamental structure of the model for each tanker type is:

P[spill of a given size and commodity] =

P[casualty type]

times

P[spill | casualty]

times

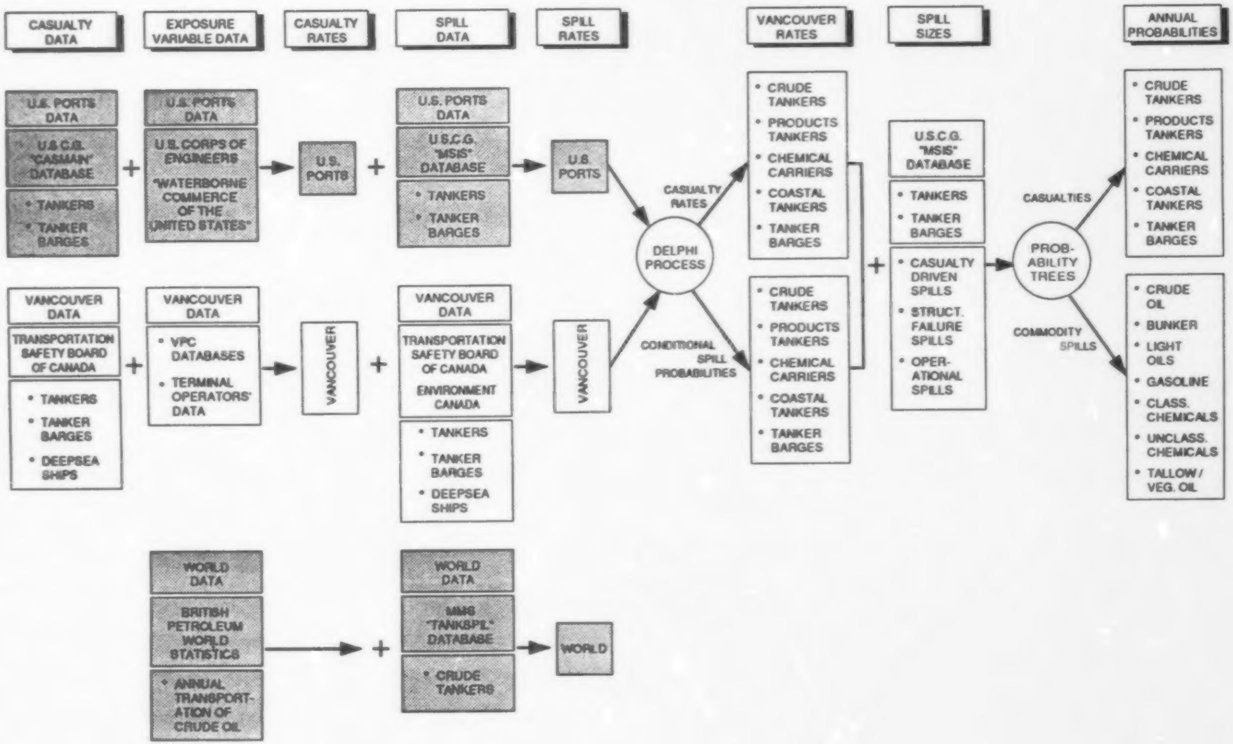
P[commodity | tanker type]

times

P[spill size | spill, tanker type, casualty type and commodity]

and the probability of a spill of given size and commodity is the sum of the probabilities of spills by each type of casualty. The final result in the VPC study was an estimate of the probability distribution of spill sizes for each tanker category, and an aggregate for the port. The model was simplified for this paper by eliminating tanker type and commodity as variables.

FIGURE 2
PROBABILITY MODEL - LOGIC DIAGRAM


CASUALTY DATA
EXPOSURE VARIABLE DATA
CASUALTY RATES
SPILL DATA
SPILL RATES
VANCOUVER RATES
SPILL SIZES
ANNUAL PROBABILITIES
U.S. PORTS DATA
U.S.C.G. "CASMAN" DATABASE
• TANKERS
• TANKER BARGES
+
U.S. PORTS DATA
U.S. CORPS OF ENGINEERS
"WATERBORNE COMMERCE OF THE UNITED STATES"
U.S. PORTS
+
U.S. PORTS DATA
U.S.C.G. "MSIS" DATABASE
• TANKERS
• TANKER BARGES
U.S. PORTS
VANCOUVER DATA
TRANSPORTATION SAFETY BOARD OF CANADA
• TANKERS
• TANKER BARGES
• DEEPSEA SHIPS
+
VANCOUVER DATA
• VPC DATABASES
• TERMINAL OPERATORS' DATA
VANCOUVER
+
VANCOUVER DATA
TRANSPORTATION SAFETY BOARD OF CANADA
ENVIRONMENT CANADA
• TANKERS
• TANKER BARGES
• DEEPSEA SHIPS
VANCOUVER
WORLD DATA
BRITISH PETROLEUM WORLD STATISTICS
• ANNUAL TRANSPORTATION OF CRUDE OIL
+
WORLD DATA
MMS "TANKSPIL" DATABASE
• CRUDE TANKERS
WORLD
DELPHI PROCESS
CASUALTY RATES
CONDITIONAL SPILL PROBABILITIES
• CRUDE TANKERS
• PRODUCTS TANKERS
• CHEMICAL CARRIERS
• COASTAL TANKERS
• TANKER BARGES
• CRUDE TANKERS
• PRODUCTS TANKERS
• CHEMICAL CARRIERS
• COASTAL TANKERS
• TANKER BARGES
+
U.S.C.G. "MSIS" DATABASE
• TANKERS
• TANKER BARGES
• CASUALTY DRIVEN SPILLS
• STRUCT. FAILURE SPILLS
• OPERATIONAL SPILLS
PROBABILITY TREES
CASUALTIES
COMMODITY SPILLS
• CRUDE TANKERS
• PRODUCTS TANKERS
• CHEMICAL CARRIERS
• COASTAL TANKERS
• TANKER BARGES
• CRUDE OIL
• BUNKER
• LIGHT OILS
• GASOLINE
• CLASS. CHEMICALS
• UNCLASS. CHEMICALS
• TALLOW / VEG. OIL

Tanker casualties and cargo spills were treated as Poisson processes with dis-aggregated mean casualty rates. With the nature of the Poisson model, it is possible to express each of the steps of the model as a Poisson casualty rate. In particular, an overall casualty rate for tanker casualties can be dis-aggregated into:

- particular kinds of casualties such as collisions;
- casualties for which spills occurred; and
- casualties for which spills exceeding a particular size occurred.

The most common exposure variables for tanker risk analyses in past studies have been vessel movements, tonnage of cargo and port calls. Although others have been suggested in research papers, they have generally been impractical to use because of the lack of data or amount of effort to obtain the data. Port calls were chosen as the exposure variable in the VPC study.

Tanker Casualties

Tanker casualties of any kind are the first level of the model. All tanker casualties were chosen as the starting point to make full use of the data available, and to allow comparisons between casualty rates for tankers and other kinds of ships.

As described above, the impact of small sample sizes and the probabilistic nature of the casualty rate (lambda or λ) make appropriate the extension of the simple Poisson model into a negative binomial distribution. A comparable method of treating this extension is to use the Poisson model but to calculate the mean casualty rate as (observed casualties plus one) divided by the value of the exposure variable. This approach was taken throughout the data analysis section of this paper. Note that in cases of zero observations, one calculates the mean casualty rate as one divided by the exposure variable value.

Tanker casualties were divided into several categories defined above: collisions, groundings, strikings, fires/explosions and structural failures. Casualty rates were defined and measured for each category.

Spill Incidence

Although spill incidences could be taken directly as a Poisson process with their own casualty rates, they were treated as conditional probabilities in this study; the probability that a spill occurs given that a tanker casualty has taken place. This approach was chosen to allow estimates of the conditional probability from various sources.

The incidences of spills are expressed in this study as the average number of casualties that are encountered before a spill occurs - the inverse of the conditional probability. This approach was chosen because the resulting variable is easier to conceptualize that the probability itself, and either can be used in a probabilistic calculation.

Commodity Type

In the VPC study, tankers were divided into several types: deepsea crude oil tankers, petroleum products carriers, chemical carriers, coastal tankers, and coastal barges. Although crude oil tankers carry only crude oil, the other kinds of vessels can carry a variety of commodities. A probabilistic variable was added to the model to account for this.

Spill Size

An opportunistic approach was taken to the choice of models for spill size for each vessel category. The gamma and lognormal distributions were chosen because of their flexibility regarding shape, and were tested empirically against the data. The distribution that provided the best fit was chosen in each case.

Driving Variables

The driving variables of the probabilistic calculation are the numbers of vessels per year in each category calling at a port. This approach allows the variation of traffic levels to assess the change in risk exposure of the port with alternative traffic forecasts.

Calculation Methods

A probability tree calculation was chosen to work through the combinations of probabilistic variables necessary to proceed from the probability of a tanker casualty to distributions of spill sizes by commodity type. Figure 3 presents the overall structure of the tree for Vancouver Harbour. From left to right it comprises:

- the type of casualty and its casualty rate;
- the probability of a spill given a casualty;
- the probability distribution of commodity type (which applies only in cases involving multiple commodities in one tanker type);
- probability of spill size given type of tanker, type of commodity and type of casualty.

The probability tree takes as inputs the driving variable (number of tankers per year in the tanker category) and individual probabilities associated with each tree branch, calculates the tip values (expected number of casualties that result from the combination of events that lead to that tip and the probabilities of the casualties), and presents summary results. These include the casualty rates by spill size for those that result from casualties, the casualty rates by spill size for operational spills, and summary results from the Poisson distribution such as the probability of one or more spills each year or the probability of one or more spills in 25 years.

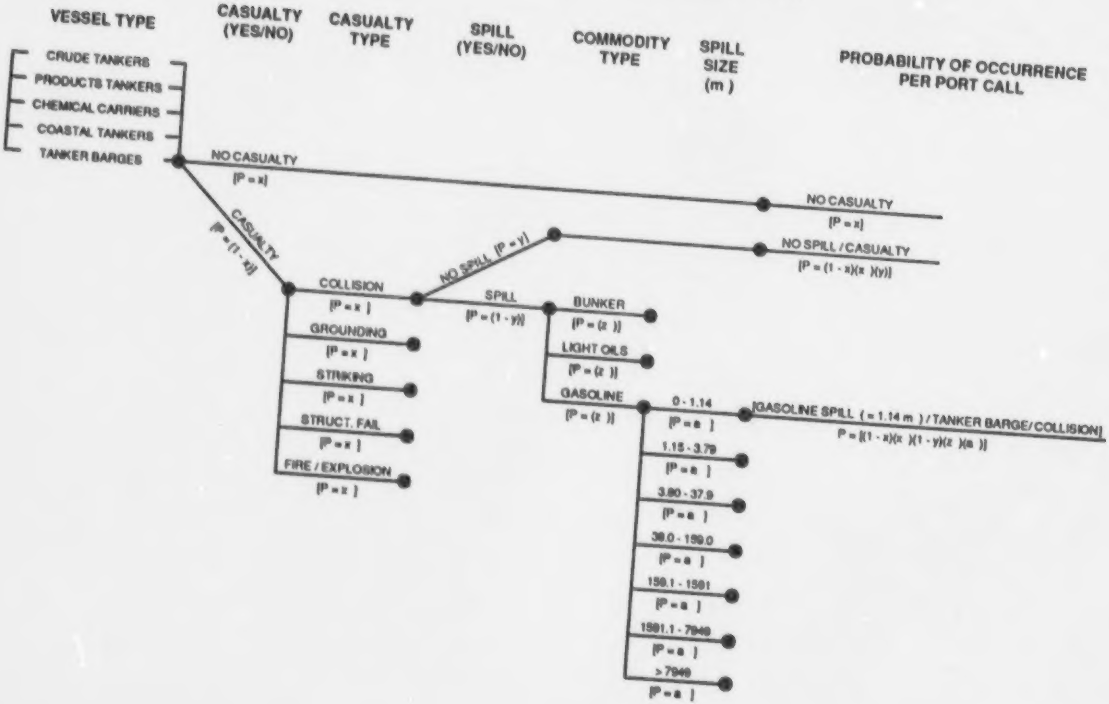
Data Analysis

An opportunistic approach was taken for data selection and analysis to make the best use of the data that was available. In general, two characteristics were expected and encountered in this work: that the Port of Vancouver data was inadequate in itself to generate casualty rates to the level of detail needed in this study, and that transformation of data from elsewhere was necessary.

In the transformation of the data, a direct approach was taken to assemble the best available data from the various sources and to use a panel of experts on the Port of Vancouver to assist in its interpretation for the port. A modified form of the Delphi technique was used for the work with the panel.

FIGURE 3

PROBABILITY TREE FOR VANCOUVER HARBOUR


VESSEL TYPE
CASUALTY (YES/NO)
CASUALTY TYPE
SPILL (YES/NO)
COMMODITY TYPE
SPILL SIZE (m)
PROBABILITY OF OCCURRENCE PER PORT CALL
CRUDE TANKERS
PRODUCTS TANKERS
CHEMICAL CARRIERS
COASTAL TANKERS
TANKER BARGES
NO CASUALTY
[P = x]
CASUALTY
[P = (1 - x)]
COLLISION
[P = x]
GROUNDING
[P = x]
STRIKING
[P = x]
STRUCT. FAIL
[P = x]
FIRE / EXPLOSION
[P = x]
NO SPILL [P = y]
SPILL
[P = (1 - y)]
BUNKER
[P = (z)]
LIGHT OILS
[P = (z)]
GASOLINE
[P = (z)]
0 - 1.14
[P = a]
1.15 - 3.79
[P = a]
3.80 - 37.9
[P = a]
38.0 - 159.0
[P = a]
159.1 - 1591
[P = a]
1591.1 - 7949
[P = a]
> 7949
[P = a]
NO CASUALTY
[P = x]
NO SPILL / CASUALTY
[P = (1 - x)(x)(y)]
[GASOLINE SPILL (= 1.14 m) / TANKER BARGE/ COLLISION]
P = [(1 - x)(x)(1 - y)(z)(a)]

The application of the Delphi technique to this problem was an interesting exercise in itself. Although it is not possible to discuss the work because of client confidentiality, the general approach is summarized below. The Delphi process addressed three questions:

- given the overall casualty rates observed for tankers and all ships in Vancouver and tankers in other ports, what inferences should be drawn about the overall casualty rate for all tankers in Vancouver;
- how should the overall casualty rate for all tankers be modified for the individual categories of tanker ships used in this study - deepsea crude oil tankers, chemical carriers and petroleum products carriers, and coastal petroleum products tankers;
- how should the tanker spill incidences by vessel type observed for other ports be interpreted for Vancouver.

The general approach taken to this work was to present the data to a panel of experts from the Port of Vancouver, use a modified Delphi process to obtain the opinion of the Panel on the data modifications, and to use the panel response as one input to the adjustment of the raw data.

DATA COLLECTION

The development of spill frequencies requires good sources of data over a reasonable period of time. The following sections outline the available sources of data, their relative merits and limitations, and finally the sources which were used in this analysis.

Availability of Data

Vessel Casualty Databases

There are several data sources available for vessel casualties. Most deal with all vessel types, although the obvious interest for this study is casualties involving at least one tanker or tanker barge. The following list presents the vessel casualty databases which were considered for casualty rates.

- Lloyd's Maritime Information Services - "Casualty and Demolition Database", and "Tanker Casualties Resulting in Oil Pollution".
- Transportation Safety Board of Canada, Marine Investigations
- United States Coast Guard, "Casmain Database"

Vessel Exposures

There is no shortage of data on vessel casualties, but in order to develop casualty rates in a port area it is necessary to know how many vessels called there over a particular period - the exposure variable in this study. Acquiring good exposure variable data proved to be more difficult than obtaining vessel casualty data. Below are the sources of exposure variable data which were investigated in the course of this study.

- Corps of Engineers, "Waterborne Commerce of the United States"

- Journal of Commerce
- Lloyd's Maritime Information Services - "Ship Movements Database"
- Port Authorities

Spill Databases

Information on spills was sought which would combine with the vessel casualty informatio to provide coherent conditional spill probabilities. In addition, spill databases are required i order to develop spill size distributions to estimate probabilities of occurrences of specific spil sizes. Below are the sources of data considered in this study.

- Environment Canada - "Spill Report Database"
- United States Coast Guard - "MSIS Database"
- United States Department of the Interior, Minerals Management Service - "Tankspil Database"

Study Data Sources

The above review showed that the best available and most appropriate information for th study covered the U.S. ports. Data was available on vessel casualties, cargo spills an numbers of port calls.

Vessel Casualties

- U.S. Coast Guard "Casmain" database.
- 55,000 records from 1981 to 1989 downloaded from USCG mainframe computer an manipulated by PC by Sandwell.

The ports selected the study were:

- Boston
- New York City
- Los Angeles/ Long Beach
- San Francisco Bay Area Ports
- Puget Sound Ports - Anacortes, Seattle, Tacoma.
- Other high-volume areas such as the Houston Shipping Channel and the Delaware Rive were ruled out because the navigational constraints in these locations are dissimilar t Vancouver's.

Vessel Exposures

- Corps of Engineers "Waterborne Commerce of the United States".

Spills

- U.S. Coast Guard MSIS database.

- Correlation between the Casmain database and the MSIS database was done manually using vessel names and dates of incidents.

- The MSIS database was also used to establish spill size distributions for different causes of spills.

Casualty Statistics

The casualty statistics presented below are based on the analyses using the databases described above. The actual rates have been presented in terms of number of casualties per 10,000 port calls. If the number shown is divided by 10,000, it would then represent the "lambda" (λ) in a Poisson probability distribution. The rates shown also reflect the small-sample methodology for calculating lambda; this method is described above: lambda = (actual number of casualties + 1) divided by number of port calls.

Casualty Rates

Tables 1 and 2 show the casualty rate breakdown for tankers and tanker barges for the selected U.S. ports. The casualty rates in the case of tankers are aggregated for all tanker types; no distinction is made between crude tankers or chemical or products tankers. In addition, the casualty rates have been presented in several different ways: the casualty rates for individual port areas, and aggregates for all port areas and for all west coast ports.

Table 1 - U.S. Ports Vessel Casualty Statistics
Tankers Only
Number of Casualties per 10,000 Port Calls

Casualty Type	Boston	New York City	L.A./L.B.	San. Fran.	Puget Sound Ports	All U.S. Ports	West Coast Ports
Collisions	5.9	3.4	5.5	2.9	4.1	3.8	3.4
Groundings	7.9	8.8	1.6	8.1	4.1	7.2	4.6
Strikings	11.8	6.5	5.5	5.2	8.3	6.5	5.2
Fires/Exp	7.9	1.6	0.8	4.1	2.1	2.4	2.0
Structural Failures	7.9	1.8	1.6	1.2	2.1	2.0	0.9
Probability of Any Casualty	33.4	21.2	11.7	19.2	12.4	19.1	14.9

Notes: Discrete probabilities for each casualty type do not sum to the probability of any casualty because of the nature of the small-sample probabilistic calculations.

L.A./L.B.: Los Angeles/Long Beach

Puget Sound Ports: Anacortes, Seattle, Tacoma

Table 2 - U.S. Ports Vessel Casualty Statistics
Tanker Barges Only
Number of Casualties per 10,000 Port Calls

Casualty Type	Boston	New York City	L.A./ L.B.	San. Fran.	Puget Sound Ports	All U.S. Ports	West Coast Ports
Collisions	1.6	5.9	2.0	2.2	1.0	2.9	1.6
Groundings	14.4	7.5	0.5	2.2	0.3	3.1	0.5
Strikings	8.0	11.1	1.4	3.3	1.3	4.5	1.5
Fires/Exp.	4.8	2.0	0.2	0.6	0.3	0.9	0.1
Structural Failure	6.4	6.6	0.6	2.8	2.3	3.0	1.2
Probability of Any Casualty	28.7	32.2	4.1	8.9	3.9	13.1	4.6

Notes: Discrete probabilities for each casualty type do not sum to the probability of any casualty because of the nature of the small-sample probabilistic calculations.

L.A./L.B.: Los Angeles/Long Beach

Puget Sound Ports: Anacortes, Seattle, Tacoma

Conditional Probabilities of Spills

A conditional probability is defined as the probability that, given a casualty has occurred, a spill will result. This may also be stated as the number of casualties that will occur on average before one of the casualties results in a spill. Table 3 presents the conditional probabilities observed according to the latter definition.

Table 3 - Conditional Probabilities
Number of Casualties Needed for One Spill

Casualty Type	Tankers	Tanker Barges
Collisions	3.9	3.2
Groundings	18.7	6.4
Strikings	10.0	6.8
Fires/Explosions	7.5	--
Structural Failures	1.3	1.4
Overall Average	6.2	3.6

The results in Table 3 show the individual results as well as the aggregated average for each vessel type and area. The number for groundings in U.S. ports is much higher than one would anticipate; the only explanation for this is that this category is overly influenced by grounding casualties in New York City environs and the bulk of these groundings are groundings on mud bottoms in the channels where most of the petroleum terminals are located.

Operational Spills

Operational spill occurrence rates were developed for the U.S. ports. The rates are representative only of spills which resulted from ship to ship or terminal/ship transfers. The rate was estimated at 30 spills per 10,000 port calls.

While this spill rate may seem rather high, it must be viewed in conjunction with the associated spill size distribution. Accordingly, the operational spills influence the overall probability of spills at the low end of the spill range and have decreasing influence on overall risk with increasing spill size. As noted in the following section, 50% of the operational spills are less than 40 litres (0.04 m^3) and 85% are less than 380 litres (0.38 m^3).

Spill Size Distributions

Spill size distributions have been developed for three spill cause groups:

i. Collisions, groundings, strikings, fires, and explosions.
ii. Structural failures.
iii. Operational spills.

In addition, separate spill size distributions were developed for tankers and tanker barges. The spill size distributions are based upon observed spills extracted from the U.S. Coast Guard MSIS database for all U.S. waters in the period 1981 to 1989.

The lognormal distribution fitted the data well in group i). A chi squared test confirmed no significant difference between the lognormal distribution and the observed data. The gamma distribution was found to be produce a better fit for group ii) - structural failures. Again, a chi squared test confirmed that there was no significant difference between the observed data and the gamma distribution. Table 4 summarizes the spill size distributions and associated parameters for each of the spill groups.

Table 5 compares the observed distributions with the estimated distributions used in the probabilistic calculations. Spill volumes are shown in barrels, U.S. gallons and cubic metres.

Figures 4 and 5 present the observed data and the cumulative distribution functions for tanker spills as examples of the distributions. Spill size has been plotted as the logarithm of the spill size on the bottom axis of the graph for easier interpretation. The vertical axis represents a cumulative distribution, or probability that a particular spill size is less than or equal to the value on the horizontal (x) axis.

Before these distributions could be used in the probability tree calculations, the curves had to be adjusted so that the probability of a spill greater than the vessel's capacity is zero. In other words, the spill size distribution curves had to be truncated and scaled in order to reflect the physical reality that a ship cannot spill a volume larger than its cargo size.

Table 4 - Spill Size Probability Distributions

Spill Category	Curve Type	Parameters
i) Tankers-Casualties except Structural Failures	Lognormal	Standard deviation (ln(y)) = 4.15 Median (y) = 600
i) Barges - Casualties except Structural Failures	Lognormal	Standard deviation (ln(y)) = 3.46 Median (y) = 210
ii) Tankers - Structural Failures	Gamma	Lamda = 0.35 k = 1.15
ii) Barges - Structural Failures	Gamma	Lamda = 0.47 k = 1.25
iii) Operational Spills	Lognormal	Standard deviation (ln(y)) = 1.80 Median (y) = 11.5

MINERAL MANAGEMENT SERVICES DATABASE

Mineral Management Services (MMS) of the U.S. Department of the Interior maintains one of the most extensive spill databases in the world. Although the database was not used extensively on the VPC study because of its limited focus (crude oil and petroleum product spills of over 159 m^3 [1,000 barrels]), the study authors extracted some casualty data from it.

Derivation of "In Port" Spill Rates

MMS quantifies the probability of "in port" spills as a subset of the overall risk of crude tanker spill, in terms of number of spills per billion barrels of oil transported. Anderson (1990) estimates the "in port" spill rate, based on data from 1974 to 1985, as 0.4 spills greater than 1,000 barrels per billion barrels transported. To be useful as a risk assessment tool this methodology relies on a relatively constant average tanker and cargo size.

In order to express the world average spill rate in terms of port calls, Fearnley's "World Bulk Trades" and "World Bulk Fleet" annual reports were consulted to estimate the numbers of crude oil tanker voyages and port calls. By combining the Fearnley's exposure variable data with the MMS crude spill data for the period 1974 - 1989 inclusive it was possible to address the following:

- the effect of changing world tanker fleet vessel size on the spill rate, and
- any change in the "in port" spill rate over the study period.

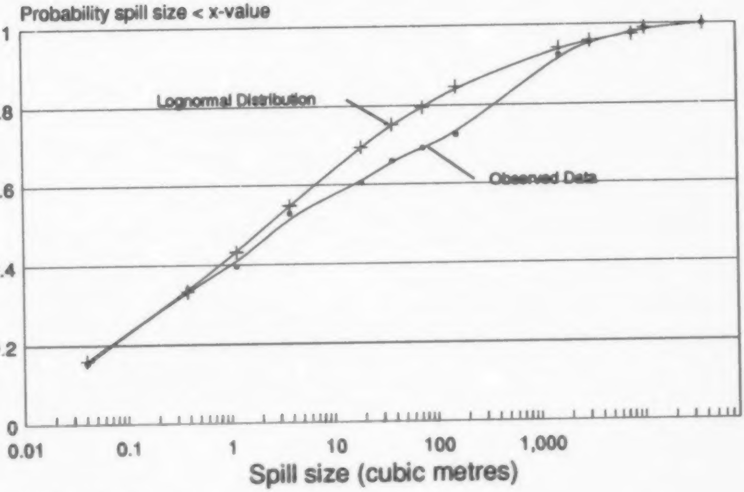
Table 6 summarizes the results of this analysis. The annual crude trade shown includes the Alaskan trade and transhipments of oil through the Suez Canal - in effect some cargoes are counted twice. In developing the number of port calls, an average of 2.5 port calls per vessel voyage has been assumed. Table 6 clearly shows the steadily increasing tanker size expressed in terms of number of tanker voyages per million tonnes of crude transported - nearly 12 voyages in 1974 declining to just under 8 voyages per million tonnes in 1980 followed by a levelling of the number of voyages per million tonnes after 1981.

Table 5 - Spill Size Distribution Summary
Probability spill size < size(x)

			Collisions/Groundings/Strikings				Structural Failures				Operational Spills	
			Tankers		Tanker Barges		Tankers		Tanker Barges		Tankers & Barges	
Volume (Barrels)	Volume (U.S. Gallons)	Volume (M^3)	Observed	Lognormal	Observed	Lognormal	Observed	Gamma	Observed	Gamma	Observed	Lognormal
0.24	10	0.04	0.154	0.160	0.161	0.189	0.465	0.487	0.538	0.585	0.509	0.4720
2.40	100	0.38	0.341	0.334	0.401	0.415	0.721	0.748	0.828	0.834	0.843	0.8600
7.14	300	1.14	0.396	0.433	0.542	0.552	0.860	0.827	0.900	0.895	0.912	0.9480
23.8	1,000	3.78	0.527	0.548	0.628	0.674	0.895	0.880	0.953	0.936	0.963	0.9870
119	5,000	18.9	0.604	0.695	0.712	0.820	0.930	0.929	0.978	0.969	0.989	0.9980
238	10,000	37.8	0.659	0.752	0.795	0.866	0.953	0.943	0.982	0.977	0.996	0.9990
476	20,000	75.6	0.692	0.795	0.833	0.907	0.953	0.955	0.986	0.983	0.997	0.9997
1,000	42,000	159	0.725	0.846	0.876	0.937	0.953	0.965	0.989	0.987	0.999	0.9999
10,000	420,000	1,590	0.923	0.942	0.988	0.986	0.977	0.984	1.000	0.996	1.000	1.0000
20,000	840,000	3,179	0.956	0.959	0.991	0.992	0.988	0.987				
50,000	2,100,000	7,950	0.978	0.975	1.000	0.995	1.000	0.990				
250,000	10,500,000	39,746	1.000	0.990								

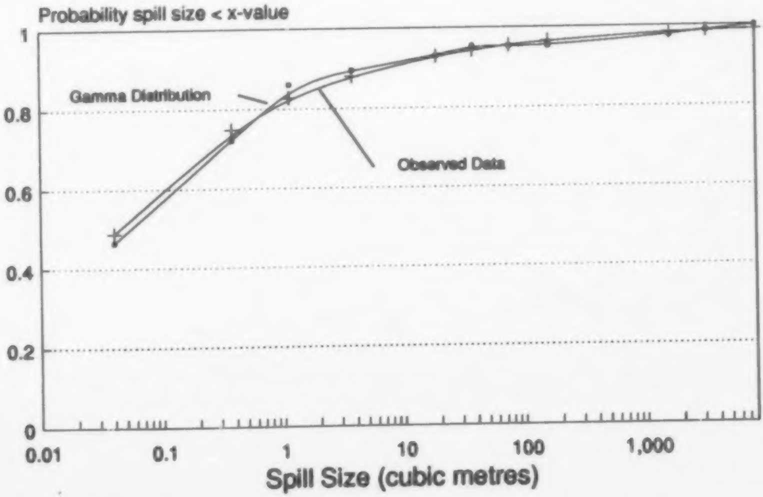
Sources: USCG MSIS Database (1980 - 1989), Minerals Management Service Database (1980 - 1989)

Figure 4 - Spill Size Distribution
Tankers-Collisions,Groundings,Strikings



Source: USCG MSIS Database/
MMS Tankspill Database

Figure 5 - Spill Size Distribution
Tankers - Structural Failures



Source: USCG MSIS Database/
MMS Tankspill Database

Table 6 - Annual Crude Trade Statistics 1974 - 1989

Year	Annual Crude Trade - Millions Tonnes	Annual Voyages	Annual Port Calls	Voyages/per Million Tonnes
1974	1,360	16,226	40,565	11.9
1975	1,259	14,641	36,603	11.6
1976	1,418	14,636	36,590	10.3
1977	1,490	13,676	34,190	9.3
1978	1,517	13,955	34,886	9.2
1979	1,606	12,561	31,402	7.8
1980	1,443	11,055	27,637	7.7
1981	1,297	10,325	25,813	8.0
1982	1,122	9,670	24,174	8.6
1983	1,014	8,758	21,896	8.6
1984	1,070	9,119	22,798	8.5
1985	986	8,570	21,425	8.7
1986	1,077	9,382	23,455	8.7
1987	1,134	9,908	24,770	8.7
1988	1,252	10,944	27,359	8.7
1989	1,375	11,975	29,488	8.7

Source: Fearnley's Bulk Trade and Bulk Fleet Reports 1974 - 1989

Table 7 below shows the results of the spill rate analysis based on the Fearnley exposure variable data and the MMS spill data. The results, expressed in terms of number of crude spills greater than 1,000 barrels (159 m^3) per 10,000 port calls, are shown for the study period 1974 - 1989 and for two subdivisions of the period. Thus, for the period 1974 - 1981 inclusive the mean spill rate was 1.42 per 10,000 port calls with an associated standard deviation of 0.23 per 10,000 port calls. For the period 1982 - 1989, the mean spill rate of 1.28 per 10,000 port calls is not significantly different than the rate for the prior period. The aggregate rate is 1.36 spills greater than 1,000 barrels per 10,000 port calls. This result represents the world average spill rate which will be compared with the U.S. study ports' rate and in the following section.

Table 7 - World Average Crude Oil Spill Rates
Spills Greater than 1,000 Barrels (159 m^3)

Year Range	Mean Rate #/10,000 Port Calls	Standard Deviation #/10,000 Port Calls
1974 - 1981	1.42	0.23
1982 - 1989	1.28	0.26
1974 -1989	1.36	0.17

DISCUSSION

The focus of this paper has been on the development of a probabilistic model for predicting bulk liquids spills which uses statistics derived for several U.S. ports as a basis for formulating local port casualty and spill rates. It is worthwhile to compare the spill rates derived from the U.S. study ports with the world average rates predicted from the MMS and the Fearnley bulk trade data derived in the preceding section of this paper. By combining the casualty rates for "All U.S. Ports" from Table 1 with the conditional probabilities from Table 3 and the spill size distributions in Table 5 one can estimate the probabilities of spill events according to size.

In order to compare the above spill rates with the other two methods a fictitious port with the following simplified parameters was assumed:

Commodity:	Crude Oil
Number of port calls per year:	1,000
Average tanker size:	125,000 dwt
Average cargo size:	112,500 tonnes
Annual port throughput:	0.83 Billion Barrels

For comparative purposes only spills greater than 1,000 barrels (159 m^3) are considered. Table 8 below shows the results of this comparative analysis in terms of probability of spill per year and average time between spills. The results have been rounded to the nearest half year.

Table 8 - Comparison of Spill Rate Predictions
Example Port - 1,000 Port Calls per Year

Method	Probability of Spill/Year	Average Time Between Spills
MMS/Fearnley Data (1)	0.14	7.5
U.S. Study Ports	0.06	16

(1) World average rate developed using MMS casualty data and Fearnley's exposure variable data.

Table 8 shows a significant difference between the probability of spill between the MMS/Fearnley based rate and the average U.S. Study Ports rate. The results indicate that the U.S. ports considered are more than twice as "safe" as the world average.

No attempt has been made to explain the differences in spill rates between the port areas shown in Table 1 above. However, the results, in general are in line with the complexity of the port geography - for example Los Angeles/Long Beach has a relatively low casualty rate which is expected given the relative lack of navigational hazards and straightforward traffic separation scheme.

It is interesting to note that tanker barges have a lower casualty rate than do tankers - see Tables 1 and 2. This is in agreement with the findings of others - notably the Bureau of Management Consulting in their work for Canadian Coast Guard. However, some of this difference is eroded by the higher conditional probabilities of spills for barges than tankers. There is a larger difference between east and west coast U.S. casualty rates for barges than for tankers. No explanation has been sought for this difference.

CONCLUSIONS

This paper describes the methodology used in estimating the probability of bulk liquids spills in the Port of Vancouver. The study terms of reference required that a variety of vessel types, commodities and spill size ranges had to be considered. To carry out this assignment it was necessary to collect and compile data rather than rely on other tanker spill risk assessment methodologies as these typically consider only crude oil spills greater than 1,000 barrels (159 m^3).

After a review of available databases, work by others and the nature of Vancouver Harbour, the following approach was used in the VPC study:

- Vessel casualties and port calls were used as the driving variables in the study. As casualties are more frequent than spills, this enabled a more ready comparison between port areas. Port calls were used as the exposure variable so that the effects of varying cargo sizes could be disregarded in the development of casualty rates.

- Conditional spill rates were developed in order to calculate probabilities of spills given a vessel casualty.

- Spill size distributions were developed so that when combined with casualty and conditional probabilities, probabilities of specific spill size ranges could be calculated.

- Spill statistics were developed from five U.S. port areas which handle significant volumes of bulk liquid cargoes. Experience had shown that valid spill statistics could not be developed with a size-limited database. The basis of the vessel casualty data was the U.S. Coast Guard Casmain database; spill data was derived from the U.S.C.G. MSIS database and the U.S. Army Corps of Engineers Waterborne Commerce records were used for the exposure variable data.

- An opportunistic approach was used to transfer the U.S. data to Vancouver Harbour; a modified Delphi technique was used to carry out this transformation. The results of this process and the final casualty/spill rates for Vancouver are not included in this paper.

- The poisson process formed the basis of the probabilistic model which ultimately forecasted average times between spills of a complete range of sizes and commodities.

The results of this work - truncated before the development of Vancouver casualty rates is summarized principally in Tables 1 - 3. Spill size distributions are presented in Table 5 and Figures 4 and 5. Based on this analysis the following conclusions are made:

- The aggregate U.S. study ports tanker casualty rate is approximately 19 casualties per 10,000 port calls; this compares with an average of 15 casualties per 10,000 port calls for the west coast U.S. ports considered.
- The aggregate U.S. study port tanker barge casualty rate is approximately 13 casualties per 10,000 port calls; this compares with only 5 casualties per 10,000 port calls for the west coast U.S. ports considered.

An overview of world crude oil casualties and spills was made. As part of this work spill rates were developed using the MMS database for spills greater than 1,000 barrels and Fearnley's world bulk trades and fleet data for exposure variables. The resulting spill rate was 1.36 spills greater than 1,000 barrels per 10,000 port calls.

A comparison of the world average spill rate calculated from MMS and Fearnley's based data was made with the spill rate estimated for the U.S. study ports. The comparison considered a fictitious port which receives 1,000 crude oil tanker port calls per year; only spills greater than 1,000 barrels (159 m^3) were considered. The results of this comparison showed:

- The MMS/Fearnley's based rates forecast an average time between spills of 7.5 years.
- The U.S. study ports rate forecasts an average time between spills of 16 years - a difference of over twice the world average time. This implies that the U.S. ports considered are significantly safer than the world average.

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A FORMALIZED RISK ANALYSIS PROCEDURE FOR OIL AND CHEMICAL SPILLS IN COASTAL AND INLAND WATERS

by

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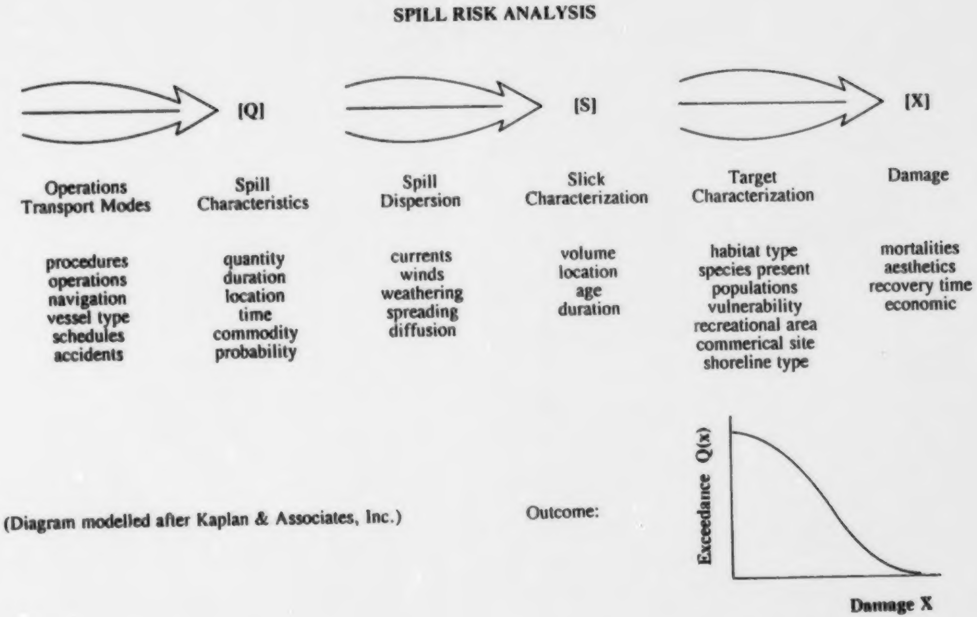
1.0 INTRODUCTION

In general, major hazardous commodity spills in coastal waters would have significant environmental and economic impacts for the region. It is also true that the degree of impact would depend upon where the spill occurs, the type and volume of commodity, the time of day and season of the spill, and the environmental conditions prevailing at the time. The purpose of risk analysis is to attempt to quantify, in a formal way, the likelihood of incurring certain environmental and economic impacts, taking all of the above factors into account.

An oil or chemical spill analysis could be described in terms of three basic segments (Fig. 1): one defining the characteristics of the spill, one giving the characteristics of the surface or subsurface dispersion process, and one expressing the impacts or damages that could result. Each segment is represented by the symbols Q, S, and X.

The arrow preceding each of the segments represents a vector of events or operations leading up to quantities contained in the segment. Within the context of accidental spills on water, these vectors can be classified as: operations and transport modes; transport and dispersion processes; and target characterization. For example, an accidental oil spill leads to characteristics in Q that include the quantity of oil spilled and the duration of the spill, the time of year and day, the chemical composition of the material, and the likelihood of the accident. Each of these parameters is determined by the commodity being transported, the operations to handle this commodity in a port, and the mode of transport (e.g. barge or tanker).

The convergence of lines in the vector serves to illustrate that different types of operations or events could produce the same spill Q, but that once this spill occurs, the subsequent events do not depend on what caused the spill in the first place. This notion applies to the other segments in Fig. 1 the same way.


SPILL RISK ANALYSIS
[Q]
[S]
[X]
Operations Transport Modes
Spill Characteristics
Spill Dispersion
Slick Characterization
Target Characterization
Damage
procedures
operations
navigation
vessel type
schedules
accidents
quantity
duration
location
time
commodity
probability
currents
winds
weathering
spreading
diffusion
volume
location
age
duration
habitat type
species present
populations
vulnerability
recreational area
commerical site
shoreline type
mortalities
aesthetics
recovery time
economic
Outcome:
Exceedance Q(x)
Damage X

(Diagram modelled after Kaplan & Associates, Inc.)

Figure 1 General framework for spill risk analysis.

Segment S denotes the outcome of the natural forces governing dispersion of the commodity. Typically it contains parameters describing the location and volume of oil at various times after the spill, the age of the oil at a particular location, and the duration that oil may be present. These quantities may be calculated, for example, with an oil motion and fate model. The parameters in S are determined by the requirements to translate target characteristics into a measure of damage.

Target characterization refers to the process of cataloguing natural, commercial, and recreational entities in the area that can be affected by the spill. These entities are mapped onto the geographical area in such a way that they can be combined with the slick parameters, S, to estimate damage. Thus, in addition to quantifying the targets (e.g. wildlife populations), the process of target characterization leads also to rules for translating the impact of the oil on the targets into whichever measure of damage has been selected.

Environmental damage from a spill can be expressed in many different ways, such as the number of birds or fish killed, the amount of habitat area destroyed or polluted, or even the length of time required for the environment to recover to its pre-spill state. This last measure of impact has the advantage of providing a common unit (e.g. years) for all the environmental impacts. Yet even this measure is limited as it does not easily take into account the economic damages that may result from, for example, lost use of the port, cleanup costs for beaches and shorelines, or the direct costs for the emergency response and spill countermeasures operations.

Considering the variety of spill damages that are likely to result in a developed coastal area, the risk analysis is often formulated in terms of damage in dollars. Of course, there is always the difficulty of expressing fish, bird and mammal mortalities in dollar terms; however, reasonable assumptions can usually be made, particularly when the approach of "upper bounding" the costs is adopted. The outcome of a risk analysis is generally expressed in the form of a conditional risk curve (Fig. 1). In deriving this curve it has been assumed that the accident has occurred; the curve relates the probability Q(x), which ranges between 0 and 1, of exceeding a certain damage X, expressed in dollars.

Because the time of the spill and many of the environmental factors occur randomly, any one, unique combination of them yields only one estimate of the damage caused by the accidental spill. By examining all factors in different combinations, and accounting for their probability of occurring at the time of a spill, one obtains a conditional risk curve for damage that is likely to result from the spill at any time throughout the year.

2.0 THE RISK MODELLING PROCESS

2.1 Accident Scenarios

The overall structure of the risk analysis is shown in Fig. 2. The risk of accidental spills from all vessel traffic in a particular waterway is usually considered in terms of a number of scenarios. Each scenario specifies the type and volume of commodity spilled, the spill location and spill duration, the time of spill (related to tide phase), and the probability of a spill of a certain size occurring. This probability is related to the volume of traffic, or the nature and frequency of operations in the area. A conditional risk curve is obtained for each scenario. Once the scenario information is known, then it remains to calculate the environmental and commercial damages for the different effects giving rise to varying impacts.

2.2 Simulations Within a Scenario

Within confined coastal areas the impacts from a spill are largely related to where the spilled commodity is transported by the currents and wind, as well as to how long it remains on the water. Natural variations in currents, winds and air temperature are treated within the risk modelling process in terms of a series of simulations. The residence time on the water is mainly governed by the recovery operations, the degree to which the liquid adheres to the shoreline, and evaporation.

For example, the currents in the Strait of Georgia have a pronounced seasonal variation resulting from Fraser River flows, and vary strongly with the tide throughout the waterway. In addition, wind-driven effects are important in terms of transporting spilled commodities. (In contrast to more open ocean areas where wind effects often dominate spill evolution, there is often a close balance between tidal currents and wind in coastal waters.) In order to evaluate the risk of spills in this area, variations in both tidal and seasonal currents, as well as wind, must be independently considered in the simulations.

The number of simulations (for example, 32 in Fig. 2) is governed by the nature of seasonal and diurnal variations in the environmental factors, and by the temporal variations in the targets. The risk model is applied for each simulation, and yields one impact cost distribution for that particular combination of season, wind and tide. Because the risk model accounts for uncertainty in the relations between the spill characteristics and the environmental and commercial impacts, a distribution is obtained rather than a single value.

The final conditional risk curve for the scenario is then found by combining all of the separate risk curves, weighted by the probability of occurrence of each of the simulations.

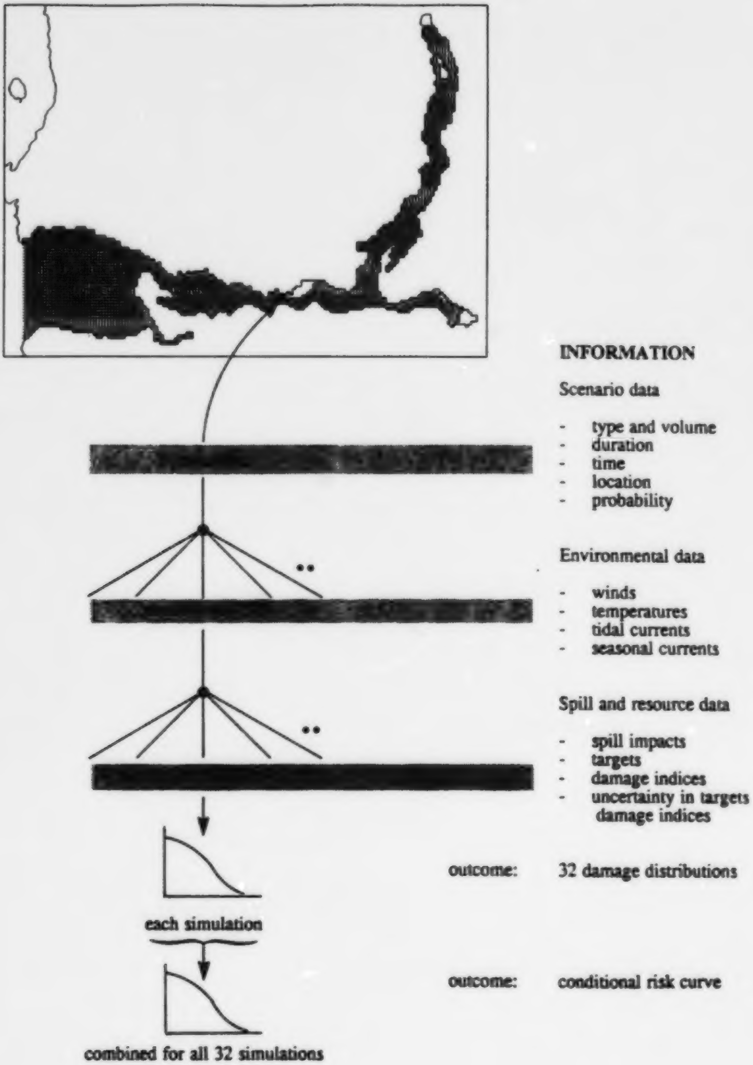

INFORMATION
Scenario data
- type and volume
- duration
- time
- location
- probability
Environmental data
- winds
- temperatures
- tidal currents
- seasonal currents
Spill and resource data
- spill impacts
- targets
- damage indices
- uncertainty in targets damage indices
outcome: 32 damage distributions
each simulation
outcome: conditional risk curve
combined for all 32 simulations

Figure 2 The risk modelling process applied to the Port of Vancouver.

2.3 Incorporating Uncertainty

Each of the targets identified for the area will contain some uncertainty arising from limitations of data defining populations, spatial distributions, utilization, or values. In addition, uncertainty will arise from assumptions made about mortalities resulting from oil and the associated costs, and from the costs of such factors as habitat restoration or shoreline cleanup. The method of dealing with uncertainty in the parameters contained in the risk model is as follows: First, a statistical distribution is derived from supporting data to describe either the natural variability found in such items as populations, or the range of values found in previous spills for costs and related factors. If the data support a particular probability density function, such as a Normal or Weibull, then such a function is prescribed in the risk model. More often the data base is insufficient to define a specific density function; in these cases a range of values to be sampled uniformly is specified, or a representative frequency histogram is given.

Second, once all the uncertainties have been specified in the risk model, the cost distribution $Q(x)$ for each of the simulations is evaluated by sampling all of the parameter functions using repeated trials. Either Monte Carlo or Latin Hypercube (see e.g. Iman and Conover, 1980) sampling can be used. The latter procedure offers advantages over the Monte Carlo method for efficient sampling of low probability outcomes represented in the input uncertainty functions. The result is more confidence in the tails of the distribution for impact costs.

The number of trials (e.g. 1000 in Fig. 2) is determined by convergence of the input distributions with the prescribed functions or data, and convergence of the risk curve.

3.0 PORT OF VANCOUVER RISK MODEL

3.1 Approach

This type of risk analysis can be illustrated through an application to the Port of Vancouver. The basic formulation has been used in a recent study of the risk of accidental spills of various commodities in the port. A hypothetical scenario is considered here, consisting of a 600 tonne Bunker C oil spill just to the west of Second Narrows, released over 4 hours. The assumed cause of the spill is a barge accident. No attempt has been made to determine the likelihood of such a spill, although the methods described by Smyth and Purdon (1991) could be used for this purpose. The slick characteristics have been calculated using the spill model described by Hodgins et al. (1991), who present typical Bunker distributions for one simulation. The spill modelling has been carried out on a 200 m grid (Fig. 2) covering the port area and all targets have been mapped in terms of the number of 200 x 200 m cells comprising the target.

In this example, the slick characteristics required for the risk model consist of two parameters for each target: (1) the number of oiled cells, and (2) the volume of oil remaining in each target area at the end of the simulation. The number of oiled cells is derived directly from maximum volume maps; one such map is shown in Fig. 3 illustrating the cells contacted by oil, and the maximum volume reaching the cell, at any time throughout the dispersion and weathering process. The volume of oil remaining in the target area is extracted from the last volumetric distribution map resulting from the spill evolution, and is directed at shoreline targets.

In the Port of Vancouver, 369 separate targets were identified, grouped into five major classes: (1) fish resources; (2) habitat resources; (3) bird resources; (4) commercial facilities; and (5) shoreline segments. The commercial facilities were further subdivided into residential areas that suffer a loss in value after a spill, parklands for which a lost use cost is incurred, marinas that require cleaning, and industrial entities along the perimeter of the port that incur various commercial losses after a spill.

An equation relating the properties of each target to a cost resulting from the spilled commodity was determined. In the case of shoreline segments, for example, estimates of the clean-up cost were made incorporating the number of crews deployed and the extent of fouled shoreline. Similarly, costs to restore sensitive habitats damaged by oil were derived from experience in the United States and Canada.

By way of an example, the treatment of wildlife populations can be illustrated using sea birds. The cost of oiled sea birds was calculated from the effort associated with recovering and treating birds following an accident. Thus the calculation involved estimating the number of oiled and recovered birds, multiplied by the handling cost. In Burrard Inlet, the total seabird count was known in each of 12 zones from winter surveys. The summer population was represented by a fraction of the winter population. Since the spill in any one simulation will contact only some of the birds in each zone during its dispersion and cleanup, that fraction has been taken as the number of oiled cells divided by the water area of the zone. Finally, only a fraction of the birds contacted by the spilled liquid will be recovered and handled as part of the emergency response activities.

Thus the cost associated with water birds during a spill can be written as

$$X_{birds}(\$) = S(nb_z)\cdot S(sb)\cdot (No_z/N_z)\cdot S(fp)\cdot S(\$b) \tag{1}$$

where $S(nb_z)$ is the number of birds in the zone during winter, $S(sb)$ is the fraction of winter birds present during summer, No_z/N_z is the fraction of oiled water cells to total water cells in the zone, $S(fp)$ is the percentage of oiled or damaged birds handled, and $S(\$b)$ is the cost for each bird handled by the response teams.

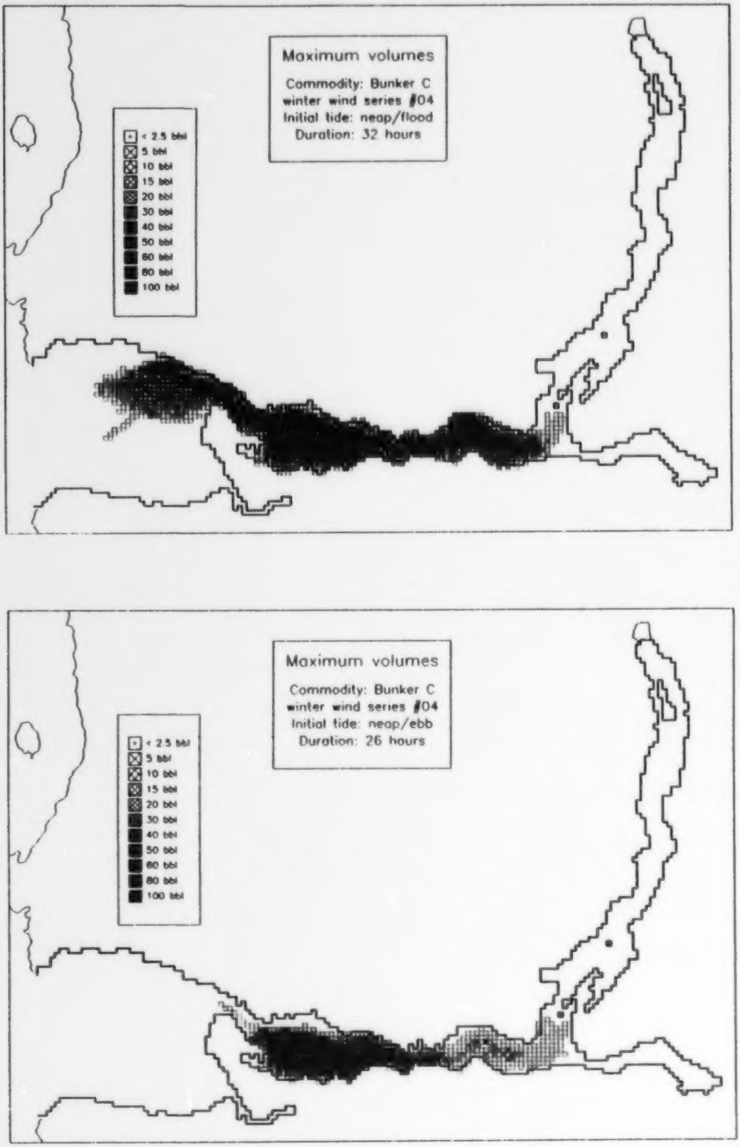

Maximum volumes
Commodity: Bunker C
winter wind series #04
Initial tide: neap/flood
Duration: 32 hours
< 2.5 bbl
5 bbl
10 bbl
15 bbl
20 bbl
30 bbl
40 bbl
50 bbl
60 bbl
80 bbl
100 bbl
Maximum volumes
Commodity: Bunker C
winter wind series #04
Initial tide: neap/ebb
Duration: 26 hours
< 2.5 bbl
5 bbl
10 bbl
15 bbl
20 bbl
30 bbl
40 bbl
50 bbl
60 bbl
80 bbl
100 bbl

Figure 3 Distribution maps for the maximum volume of oil over all cells in the Port of Vancouver. Tidal conditions are: flood spill (upper panel) and ebb spill (lower panel).

The parameters $S(nb_z)$, $S(sb)$, and N_z are contained in the target characterization. The number of oiled cells No_z is calculated by the spill model and forms an entry in S. Equation (1) is the rule connecting the targets and spill characteristics with the damage X; it contains the cost information relating targets and damage in economic terms. All 369 targets in the risk model have similar data and rules to give the total damage vector X.

In this example of water birds, the damage equation contains four parameters related either to the population of birds that can be present in the zone at any particular time, or to the number of damaged birds that could be handled and rehabilitated, and the associated cost. The bird populations are subject to large natural variations from year to year and season to season; thus, there is statistical uncertainty associated with the population that would be present at the time of a spill. Similarly, recovery and cost figures for birds vary widely from one spill to another, and there is considerable uncertainty in these parameters.

Variations in each of these parameters were specified in the risk model for the sea bird targets, and in a similar manner for all other targets.

In addition to the costs related to damage to each of the targets in the above five classes, there are two other components leading to direct costs after a spill. These are the cost of the containment and waterborne cleanup operations, and the management costs incurred by all the agencies that would participate in the cleanup effort. The emergency response costs have been estimated using per diem rates for equipment and personnel. Management costs include items such as helicopter rentals, coordination centre costs, communications and related day-to-day business expenses, and have been included as a multiplier on the direct spill costs.

3.2 Simulation Impact Distributions

As a result of introducing the uncertainty of various parameters into the risk model, the outcome for one simulation is a cost distribution. Using the 600 tonne Bunker spill as the example, the expected costs in each major target class are shown in Fig. 4 for a simulation corresponding with flood release on neap tides The wind conditions were chosen at random from the long-term data base measured at Pt. Atkinson. The impact distribution is presented in Fig. 5; the expected total cost is $40,007,547.

The table in Fig. 4 shows that expected damages ranged from a low of $44,992 for marinas, to a high of $14,040,265 for shoreline cleanup. Each of the target entries in this table has a statistical cost distribution associated with the expected value--the spread of these distributions reflects the uncertainty in each damage estimate. The mean damage cost, plus and minus one standard deviation, and the 5% and 95% limits for each target

```
Global Scenario Parameters                |=====Expected Costs=====|
    Bunker                                |========================|
    Winter                                |  Vancouver |  Target   |
    Neap Tide                             |   Harbour  | Sub-Class |
    Flood Start                           |Cleanup Cost| Sub-Total |
    Wind Series 4                         |      $     |     $     |
====================================================================
                              Total Cost: | 40,007,547             |
                                          |============            |
                    Management Fee:    25%|Management:   8,001,509 |
                                          | Recovery:      546,300 |
                                          |Fish Stock:     427,586 |
                                          |   Habitat:   6,148,242 |
        No. Shoreline Cleanup Crews:    3 |     Birds:   1,440,927 |
        Habitat Cleanup Contingency:   10%|Residential:    834,272 |
                   Volunteer Effort:   10%|  Parkland:   6,582,507 |
                                          |   Marinas:      44,992 |
                                    Target|Industrial:   1,940,947 |
ID  Target name/location            Class | Shoreline:  14,040,265 |
====================================================================
```

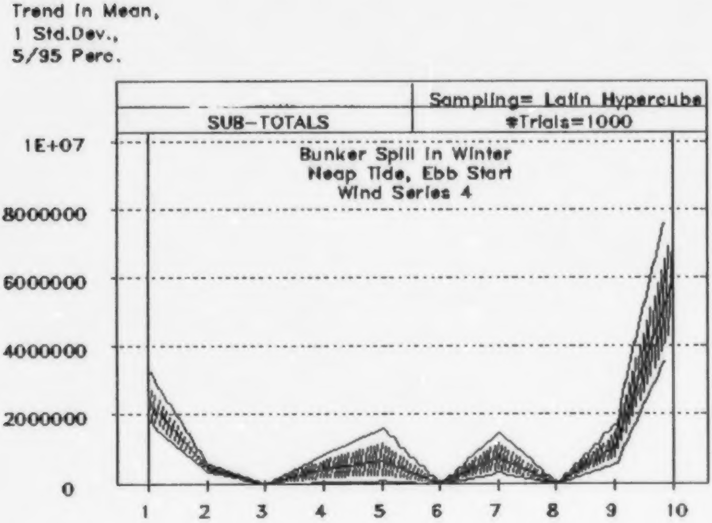
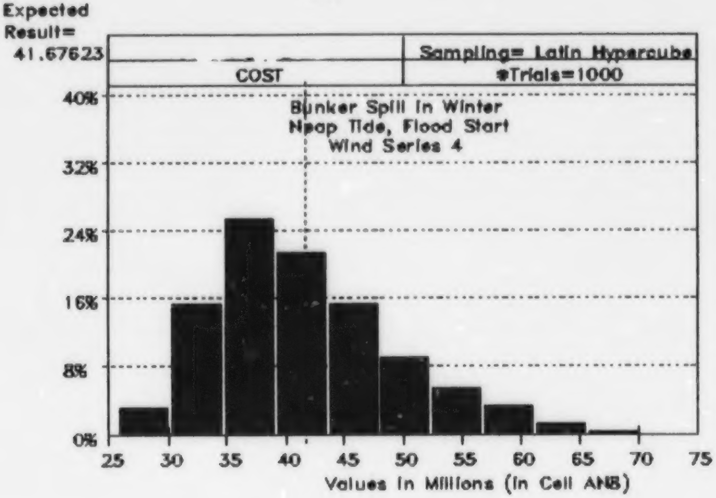


Figure 4 Summary of expected costs for all 10 target classes in the Port of Vancouver risk model (upper panel), and the variations in target class impacts (lower panel). These results correspond with flood tide spill.



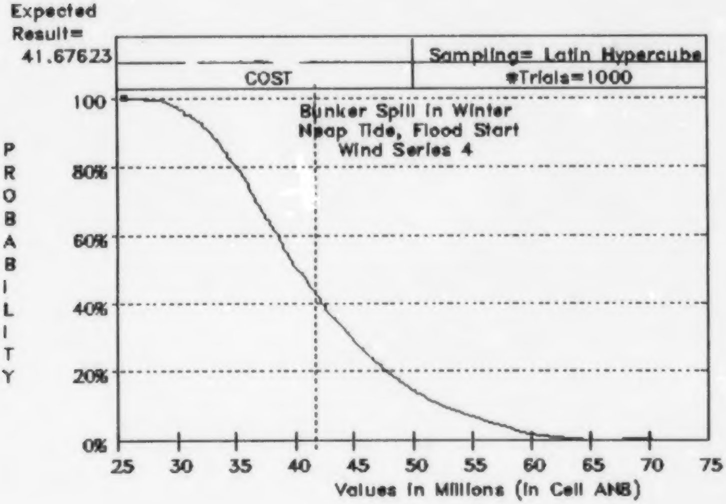


Figure 5 Histogram of total Bunker C spill costs (upper panel) and the simulation impact curve (lower panel) for the flood tide spill.

class are shown on the bottom panel of Fig. 4. It can be seen here, for example, that the shoreline costs not only have the largest expected value, but also the largest spread in potential costs. These variations in cost result from the uncertainty in the targets and the cost relationships, but not from different environmental conditions determining the dispersion of the spilled commodity.

The impact costs are also sensitive to the wind and tide conditions. In an area such as the Port of Vancouver, where the different target types are widely distributed and the main sink for spilled oil is the shoreline, the phase of the tide at the time of the spill has an important bearing on the outcome. For example, the simulation costs for the same 600 tonne Bunker spill released on ebb tide (Fig. 3), neap conditions, are shown in Fig. 6. The expected total cost has fallen to $11,611,369, primarily because shoreline and habitat costs are greatly reduced. In this simulation, wind and tide combined to distribute the oil along the south shore of the inner harbour, one of the least environmentally sensitive zones.

3.3 The Conditional Risk Curve

The final conditional risk curve is found by combining all simulation distributions weighted by their frequency of occurrence in one year. For example, in the Port of Vancouver, currents were modelled in two seasons: summer, spanning 5 months when the Fraser River dominates the upper layer dynamics in the Strait of Georgia, and winter lasting 7 months when the dynamics are less influenced by runoff. Under these conditions, the simulation risk curves for summer were weighted by 5/12 and each winter curve weighted by 7/12. The tides were modelled in two sequences: spring and neap, and the time of spill release on two phases, ebb and flood. Then by choosing four random wind time-series for each season and tide, the conditional risk curve for each scenario was formed from 32 independent simulations.

4.0 CONCLUSIONS

Risk analysis for oil or chemical spill impacts provides a quantitative measure of damage in the event of an accident. The results can be used to compare different methods for transporting liquid commodities, or to examine the changes in risk associated with improvements to port operations or to changes in land and water utilization. The risk analysis process also provides valuable insight into the environmental conditions leading to large impacts, and which economic, recreational or wildlife resources are most susceptible to damage. Moreover, the detailed modelling of spill evolution, in relation to these targets, leads to rational emergency response plans for the area of interest.

```
Global Scenario Parameters                        |=====Expected Costs=====|
    Bunker                                        |========================|
    Winter                                        | Vancouver  |  Target   |
    Neap Tide                                     |  Harbour   | Sub-Class |
    Ebb Start                                     |Cleanup Cost| Sub-Total |
    Wind Series 4                                 |     $      |     $     |
===========================================================================
                                      Total Cost: | 11,611,369             |
                                                  |============            |
                            Management Fee:    25%|Management:   2,322,274 |
                                                  | Recovery:      546,300 |
                                                  |Fish Stock:       6,681 |
                                                  |   Habitat:     524,206 |
               No. Shoreline Cleanup Crews:      3 |     Birds:     757,546 |
               Habitat Cleanup Contingency:    10%|Residential:          0 |
                          Volunteer Effort:    10%|  Parkland:     794,432 |
                                                  |   Marinas:           0 |
                                            Target|Industrial:   1,144,795 |
ID  Target name/location                    Class | Shoreline:   5,515,135 |
===========================================================================
```

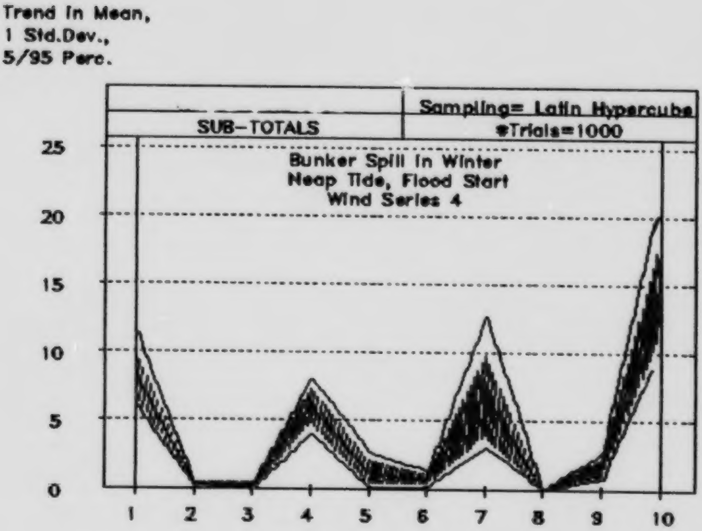


Figure 6 Summary of expected costs for all 10 target classes in the Port of Vancouver risk model (upper panel), and the variations in target class impacts (lower panel) corresponding to the ebb tide spill.

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THE USE OF ADDITIVES FOR SMOKE REDUCTION FROM BURNING POOL FIRES.

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INTRODUCTION.

At the AMOP conference, last year, Mitchell[1] presented data which showed that the iron compound, ferrocene, was very effective in reducing smoke emissions from the laboratory scale combustion of crude oil. This has obvious applications to oil spill cleanup and this research program is continuing with the ultimate goal of the developing of protocols for the use of such additives in field situations. Ferrocene is non-toxic and insoluble in water. It therefore does not present any environmental problems associated with the contamination of the marine environment. It is however not very soluble in oil and having a greater density than water, presents problems with regard to adding it to an existing spill.

A number of other iron additives have been studied and a clear picture of the mechanism for the action of such additives in soot reduction is emerging. Some of this work has recently been published[2]. The present paper describes tests which have been performed on two such additives butylferrocene and pentylferrocene. Their effectiveness and suitablility as smoke reducing agents is discussed.

A basic question in this research is the effectiveness of the ferrocene compounds in larger scale fires. A series of 1 meter diameter pool fire burns have been performed and the results are presented. Plans are in place for a series of 6 meter burns and these should have been completed by the time of the conference. An experiment has been performed in which ferrocene was introduced into an already burning fire and this was found to be successful.

FERROCENE DERIVATIVES.

Butylferrocene $(C_4H_9.C_5H_4.C_5H_5)Fe$ is a liquid with a density of 1.172 and mixes easily with crude oil. Its melting point is 10-12C and its boiling point is 232C. Burn tests were performed in which 15ml samples of Prudhoe Bay crude oil containing varying concentrations of butylferrocene were burned in 5cm diameter ceramic crucibles. The smoke from these burns was drawn through a quartz filter and the volume of the soot thus collected was measured. The results of these tests are shown in figure 1. It can be seen that butylferrocene is an excellent smoke inhibiter.

Pentylferrocene $(C_5H_{11}.C_5H_4.C_5H_5)Fe$ is also a liquid. It has a density of 1.170, a boiling point of 80-90C. It also mixes easily with crude oil. Similar burn tests were performed with pentylferrocene and the results are shown in figure 2. Again it can be seen that pentylferrocene would be very suitable for use in inhibiting smoke emission from burning oil spills.

Both these compounds have densities greater than water but they can be mixed with appropriate proportions of kerosene to produce a liquid with the same density as the crude oil.

ADDITIVE ADDITION TO EXISTING FIRES.

The question arises, Is it possible to add one of these compounds to a fire that is already burning in order to inhibit smoke production? Ferrocene is itself flammable and when burned on its own emits copious amounts of iron oxide particulates. Adding it directly into the flames of a fire will not therefore be useful in smoke supression. An experiment was performed however in which ferrocene powder was injected below the surface of a pool of burning oil. It was found that within a few seconds, the ferrocene began to dissolve in the oil and indeed a considerable reduction in smoke output was obtained. This technique could be useful in situations involving the accidental ignition of fuel tanks or wells, provided it is possible to access the region below the fire.

1-METRE BURN TESTS.

As mentioned above, although ferrocene is very effective in eliminating soot from small laboratory scale fires, one must ensure that it will work on a large scale before it can be used in the field. As a first step in determining its applicability to large fires, a series of

1 metre burn test was performed with the assistance of the Fire Safety Department at the University of Western Ontario. Burns were performed using Varsol, Varsol + 2% ferrocene, Norman Wells Crude oil and Norman Wells + 4% ferrocene. The results of these tests are shown in figures 3-6. It can be seen that in the case of Varsol alone, copious amounts of black smoke were produced. No visible smoke was produced in the case of the Varsol+ferrocene mixture combustion.

The crude oil burn also produced a considerable amount of black smoke. When the crude oil + ferrocene mixture was burned this was eliminated although there was a small amount of white smoke emitted. This is due to the iron oxide produced from the ferrocene. The difference in the two cases may mean that in fact too high a concentration of ferrocene was used in the crude oil tests.

What was particularly interesting was the fact that in both cases, when the ferrocene was used, black smoke was seen emanating from the base of the fire, at the edge of the pool, but this was rapidly destroyed within the fire and was not emitted. Also, although secondary flames were visible, high up in the fire, they did not lead to soot output. This is very encouraging and points the way to larger scale tests.

6-METRE BURN TESTS.

A series of 6 metre diameter burn tests are scheduled for the month of June 1991, and will be held at the Fire Training Facility in Calgary Alberta. These tests will involve particulate, CO_2, CO and hydrocarbon sampling and burns will be performed using both crude oil and fuel oil, with and without the addition of premixed ferrocene. It is hoped that the results can be presented at this meeting.

CONCLUSION.

The results obtained in this program to date are very encouraging and lead us to believe that the addition of ferrocene or ferrocene derivatives can be a useful and viable method of reducing smoke emissions from the combustion of oil spills.

ACKNOWLEDGEMENTS.

The generous financial support of ESSO Resources Canada Ltd and the invaluable assistance of Drs. Ron Goodman and Michael Moir of that organization are gratefully acknowledged. Thanks are also due to Mr. Mark Vansteenkiste of the Fire Safety Section at the University of Western Ontario for assistance in conducting the 1 metre burn tests.

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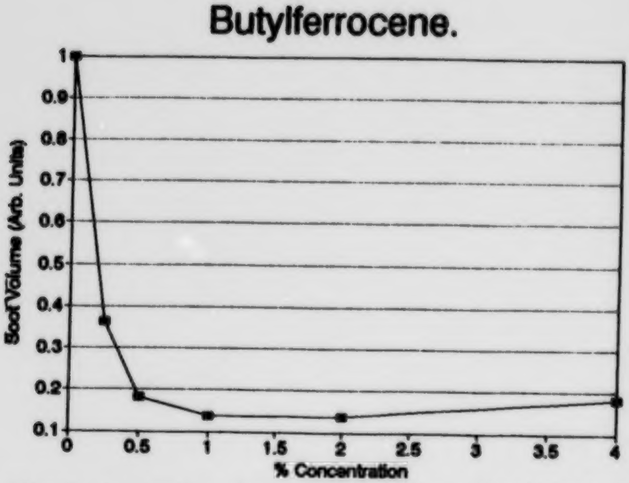

Figure 1. Soot volume emitted from the burning of butylferrocene seeded samples of Prudhoe Bay oil vs. additive concentration.

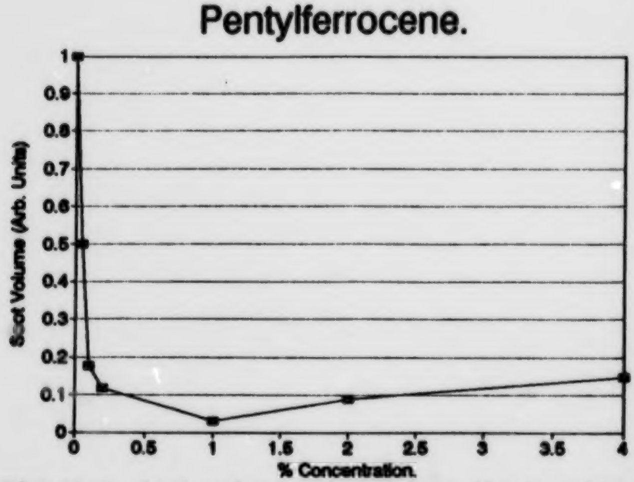

Figure 2. Soot volume emitted from the burning of pentylferrocene seeded crude oil samples vs additive concentration.

Figure 3. 1 metre Varsol burn without additive.

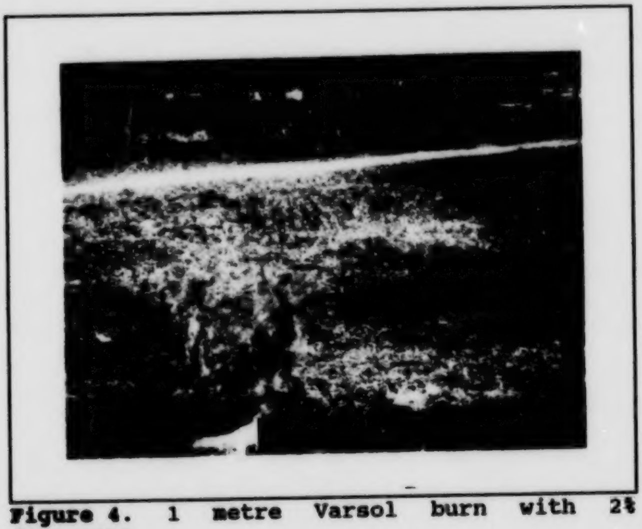

Figure 4. 1 metre Varsol burn with 2% ferrocene.

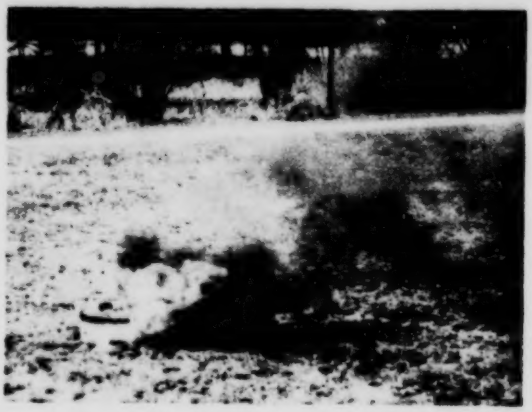

Figure 5. 1 metre Norman Wells burn without additive.

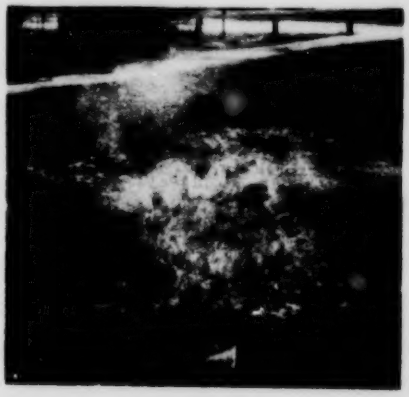

Figure 6. 1 metre Norman Wells burn with 4% ferrocene.

BURNING OF OIL IN SNOW

Experiments and implementation in a Norsk Hydro drilling contingency plan.

by

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Abstract.

A series of experiments with burning of oil/snow mixtures have been carried out. The objective was to develop practical methods for **in situ** burning of spilled oil to be implemented in the Reindalen 1 drilling contingency plan. This paper describes the results from the 8 field experiments (1000 litres each) with naturally spread oil, and two series of burns in small experimental vessels. The oil types studied were Oseberg crude oil and diesel. Efficiencies between approx. 90 % and 99 % were obtained in all the burns. It was demonstrated that oil/snow mixtures with oil concentrations with above 75% could be ignited with a rag soaked in petrol, and that concentrations as low as 3–4% (w/w) could be ignited after supply of additional petrol. Burning of oil in snow is recognized to be similar to burning of oil on water, with separation of oil and snow by melting, and formation of an oil layer on a meltwater pool as the step that determines success. Wind herding is found to be an important regulating factor. Implementation of burning of oil/snow mixtures as an oil spill mitigation tool into the Reindalen 1 contingency plan is outlined at the end of the paper.

INTRODUCTION.

Most industrial activities involve the risk of accidental pollution. In arctic areas the overall risk might increase due to severe environmental constraints, and an assumed slow recovery of vulnerable areas, if severely disturbed. In the Norwegian Arctic, industrial activity has been limited until now. However, as part of increasing interest for exploring resources in the Norwegian Arctic, Norsk Hydro in cooperation with Petro Arctic and Store Norske Spitsbergen Kullkompani; started exploratory drilling for hydrocarbons on shore on Spitsbergen in January 1991. The drilling is called Reindalen 1. Drilling activities are limited to the winter period. Both Norwegian oil companies and the pollution control authorities have limited experience with oil spill contingency in arctic winter situations. Earlier exploratory drilling for hydrocarbons on Spitsbergen have been carried out in summer, close to the shoreline. The present venture thus presents a considerable challenge to the operating company, Norsk Hydro, in finding means of reducing the potential risk to the arctic environment. Considerable efforts were put into most areas related to the environmental aspects of the drilling activities. This paper presents the main results of experiments with the **in-situ** burning of oil in snow, which is a major technique for oil spill mitigation in the oil spill contingency plan. The paper also gives a short overview of the contingency plan.

Snow will be the major substrate for the reception of oil coming from spills in arctic winter situations. Snow is a porous medium with a retention potential that depends on the snow and oil properties. Besides manual clean-up of oil contaminated snow, and subsequent removal of oil after separation by melting, few options exist to deal with this type of spilled oil. Clean-up like this would be very labour intensive, and thus not feasible for larger spills. An incentive thus existed to develop more labour saving, and efficient methods to be applied in the arctic winter situation.

In-situ burning of oil is already considered a very promising technique to be used in open water situations, and among floes in ice-infested water (e.g. Brown and Goodman,1986;Evans,1988), although restrictions in terms of weathering and emulsion formations on efficiency are known exist (Buist, 1981; Brzustowski and Twardus, 1982; Smith and Diaz, 1987; Twardus, 1980; Twardawa and Couture, 1980).

A series of **in-situ** burning experiments with oil in snow were done. The experiments were performed in connection with the oil in snow spread experiments reported by Bech and Sveum (1991), in which the spreading of both Marine diesel oil and Oseberg crude oil were studied. In addition to experiments with the burning of naturally spread oil, some experiments were done with oil artificially mixed into the snow in smaller vessels.

The main objective of these experiments was to develop practical documentation of **in-situ** burning of oil in snow,so that **in-situ** burning could be incorporated into the contingency plan for the drilling.

MATERIAL AND METHODS.

The experiments were conducted in Spitsbergen during April and May 1990. The experimental conditions were typical of those to be found during arctic winters in Spitsbergen.

Two types of oil were selected for the experiments; Marine diesel oil which is transported in connection with all types of operations in the Arctic, and Oseberg crude oil which was selected as an example of a crude oil. The characteristics of the tested oil are given in Table 1.

TABLE 1 Physical and chemical properties of the two oil types used in the burning experiments with oil in snow; i.e. Marine diesel and Oseberg crude oil.

Properties	Diesel	Oseberg crude
Density (g/ml)	0.847	0.849
Surface tension (Mn/m)		
air/oil	29	29
oil/seawater	20	21
Pour point (°C)	- 27	- 24
Flash point (°C)	55	46.1

The oil that had been released in the experiments with the burning of oil was ignited in different ways. In some experiments the oil-contaminated snow was partly collected into heaps. The oil and snow mixture was ignited with the addition of petrol. The amount necessary for successful ignition depended on the oil concentration, and the degree of evaporation.

In some of the experiments the oil was left more or less undisturbed under the snow after the spreading experiment, and only a small trench was excavated towards the centre of the spill before ignition with petrol.

In addition to the experiments with the burning of diesel and Oseberg crude oil with the distribution obtained after the spreading experiments, a series of experiments was done in small vessels with mixtures of snow and oil with known concentrations. These experiments were designed to allow an evaluation of the accurate determination of burning efficiency, as well as evaluating the effect of decreasing oil concentration on the burning efficiency. Table 2 gives a summary of all the experiments.

TABLE 2. Summary of the burning experiments. (D1, D2 etc. refers to oil spread experiments reported by Bech and Sveum 1991, this issue.)

BURNING	OIL TYPE	VOLUME OIL (litre)	VOLUME SNOW (litre)	NUMBER OF BURNS
B1	Oil from D1	1000	N.D	1
B2	Oil from D2	1000	N.D	1
B3	Oil from D4	1000	N.D	1
B4	Oil from D5	1000	N.D	1
B5	Diesel	0.25-8.0	8	6
B6	Oil from C1	100	N.D	1
B7	Oil from C2	1000	N.D	1
B8	Oil from C4	1000	N.D	1
B9	Oil from C5	1000	N.D	1
B10	Oseberg	0.25-8.0	8	6

It is difficult to evaluate the burning efficiency accurately after field burning. In our experiments the burning efficiency was evaluated from the amount of residue left on the after burn "meltwater pool", and by comparing the size of this pool with the spreading area obtained and mapped after the spreading experiments.

In the small-scale vessel experiments, all the oil was collected and measured volumetrically after the settling of the collected water phase. The exact burning efficiency could thus be evaluated.

RESULTS AND DISCUSSION

The field experiments with the in-situ burning of diesel and crude oil.

Four field trials with in-situ burning with each of the two oil types were conducted. The "response time", i.e. the time between release of the oil and the time of ignition varied from 4 to 13 days. This was intended to simulate real conditions, where countermeasures against oil spills are often limited by environmental or logistic constraints. The variability in response time, implies that the ignited oil varied to some degree in composition, i.e. the degree of natural weathering.

As expected, the results from the burning trials on water, and from experiments with snow/oil mixtures, the success of burning was very much dependent on the success of ignition. The success was established, once the oil had caught fire.

We assumed that it would be necessary to create some kind of artificial containment to achieve successful burning. However, this was not necessary with the spatial distribution the oil had in our field experiments.

TABLE 3. Estimated burning efficiency, with information on the response time, i.e the number of days from the release of oil to the time of ignition for each experiment. (D1, D2 etc. refers to oil spread experiments reported by Bech and Sveum 1991, this issue.)

Burning	Exp. type	Days after release	Estim. burn eff.
B1	Oil from D1	4	> 90%
B2	Oil from D2	12	> 90%
B3	Oil from D4	7	> 90%
B4	Oil from D5	8	> 90%
B6	Oil from C1	13	> 90%
B7	Oil from C2	13	> 90%
B8	Oil from C4	7	> 90%
B9	Oil from C5	8	> 90%

Small scale burning experiments.

As noted above these experiments were carried out in order to establish limitations in terms of oil content in snow on the burning efficiency and the method of ignition. Six individual vessels were used in these experiments. The oil concentration varied from approximately 100 %, in weight, down to approximately 3 %. The initial oil concentration together with the burning efficiencies are given in Table 4.

TABLE 4. Oil concentration and burning efficiency in the small scale experiments.

Vessel #	Oil conc. (%)	Burning efficiency %	
		Diesel	Crude
1	100	99.9	98.3
2	50 (75)	99.9	96.3
3	25	99.0	95.5
4	12.5	99.0	92.5
5	6.25	99.6	89.0
6	3.1	92.0	90.0

In the vessel with the highest concentration of oil, ignition could be accomplished with a small amount of petrol on a small rag. With the same amount of petrol on a rag, the ignition of the oil in an oil/snow mixture of 50 %, ignition was unsuccessful. Oil was then added to give approximately a 75 % concentration of oil. The burning success after increasing the oil concentration was similar to that found with the 100% concentration.

In the vessels with the lower concentrations of oil in snow, the success of ignition could be achieved by increasing the amount of petrol on the rag.

No differences in the overall burning pattern between the two oil types were found, although the crude oil gives a slightly lower burning efficiency than the diesel oil. In both cases, the maximum efficiency is close to 100 %. These small scale experiments were varied with a prevailing wind speed of approximately 10 m/sec. The walls of the vessel worked as a containment, and a pronounced wind herding effect could be observed. There were no attempts to quantify this effect by multiplying the experiment with different wind speeds. The observed lower burning efficiency of the crude can be explained from the content of asphaltens in the crude, in contrast with the diesel, however, the uncertainty of the wind herding effect make make it difficult to draw firm conclusions on this issue.

Comments on burning dynamics of oil mixed with snow.

Based on the results, and the observations of the burning, we have some comments on the in-situ burning process for oil in snow.

As for burning of oil on water, the burning success is mainly dependent on ignition success, though the mechanisms are different. Burning of oil in snow differs from oil burning on water, because oil mixed in snow does not form emulsion, this being one of the characteristics for oil on water. The evaporation rate is also slower with snow. These two features make burning of oil in snow more feasible than oil on water. When oil in snow is ignited, there are no principle differences between burning of oil in snow and oil in water. In the following discussion we refer to Figure 1, which gives a graphical overview of a conceptual model for burning of oil in snow.

The ignition has two functions. The first is to ignite the oil. Then enough heat must be formed during ignition to melt snow and form a meltwater pool. When the snow melts oil is released, which forms a layer on top of the meltwater pool. The ignition success depends on this layer, and thus on the concentration of oil in the snow. If the initial concentration of oil is low, formation of a sufficient oil layer on top of the meltwater pool depends on supply of more oil/petrol, or the use of a more efficient ignitor, which melts snow more efficiently. The properties of the snow also determine the ignition efficiency. With repeated melting and freezing, or when other factors induce ice formation, the need for heat for melting the oil/snow (ice) increases, and the heat loss rises. A greater effort is then required to ignite the oil.

The thickness of the oil layer depends on the area of the meltwater pool, which in turn depends on the way the melting process proceeds, and on the concentration of oil in the melting snow. The melting process is greatly influenced by the wind; i.e. on how the wind deflects the flames, and distributes the radiated heat. The melting will thus proceed downstream of the wind direction.

The burning process starts when enough snow has melted to give a sufficiently thick oil layer to maintain the temperature required to start the gasification process. It is not the oil that burns, but the gas formed from the oil.

Once ignited, the burning process will commence in the same manner as if we were igniting an oil slick on water. Film thickness, and thus burning efficiency is controlled by the supply of oil from melting snow, the increase in meltwater pool area, and the wind control of the spatial distribution of the oil on the pool. The burning process itself leads to a continuous reduction of oil layer thickness. If the melting process supplies the same amount of oil, as that removed by combustion, a steady state situation prevails.

Wind exposure seems to be an important factor for the burning of oil from oil/ snow mixtures. The wind works by:

- controlling the melting area, due to deflection of flames
- controlling the temperature in the oil layer, also as a result of flame deflection
- wind herding.

The first two mechanisms are well known from oil on water burns. Our experiments were done with partly significant wind speeds, without a reducing effect on burning efficiency. Wind herding is easily observed to be a positive factor, from the repeated ignition of an extinguished layer at the edge of the pool, once herding by wind reaches a certain level.

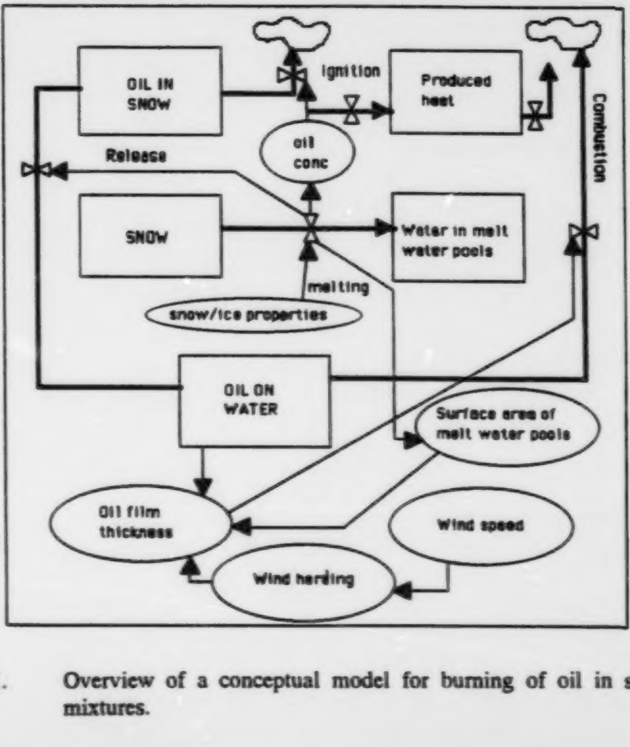
OIL IN SNOW
Ignition
Produced heat
Combustion
oil conc
Release
SNOW
Water in melt water pools
melting
snow/ice properties
OIL ON WATER
Surface area of melt water pools
Oil film thickness
Wind speed
Wind herding

Figure 1. Overview of a conceptual model for burning of oil in snow mixtures.

BURNING OF OIL IN THE REINDALEN 1 CONTINGENCY PLAN

As emphasized in the introduction, the main objective of the experiments presented above was to give practical input for the design of the Reindalen 1 drilling contingency plan. Burning of oil is the main mitigation technique in this plan, which is reviewed below:

The Reindalen 1 drilling site and the transportation route.

The drilling site is located on a slightly sloping fluvial plain on the upper part of a wide valley, called Reindalen which has given the drilling site its name. The vegetation is sparsely developed, and the higher animal life scarce. Both the drilling site and the run-off area are described in detail in an environmental atlas (Sveum and Hoddø 1990).

Transportation to and from the site is restricted to one route, i.e. from Sveagruva to Reindalen. The route which is approximately 40 km long runs mainly on frozen rivers, with moderate slopes.

Overview of the Reindalen 1 contingency plan.

The contingency plan is developed to deal both with accidental pollution both during transport of diesel to the drilling camp, storage of diesel at the camp and if a blow-out should occur during the drilling.

The main feature of the contingency plan is the distinction between frontline contingency and secondary contingency, to make up the total contingency package.

> The frontline contingency implies that one attempts to collect and/or treat entire oil spills before they are transported by natural spread more than approximately 300 metres downstream of the drilling site. A frontline contingency was established to handle a maximum blow-out rate of 2000 m^3/day for 5 days. The main feature of this frontline contingency is given in figure 2.

A large containment wall was established downstream of the drilling site. The wall was constructed from gravel, reinforced with spray ice. The construction was selected to ensure that the wall would neither be permeable to oil, nor should it melt. In the calculation of melting resistance we assumed that oil temperature was 60°C when escaping from the well out of control. It was also required that the well should resist melting during in-situ burning of collected spilled oil, although the main burning, if spills should occur, was to take place in special burning containers. The oil was to be pumped from the collection wall into these tanks.

Ignition of the oil in the tanks or in the collection walls can be done without problem, as this oil will be relatively unweathered, and with a small content of snow.

The secondary contingency was defined as that designed to deal with any spill escaping the frontline contingency. The relation between frontline and secondary contingency is shown in Figure 2.

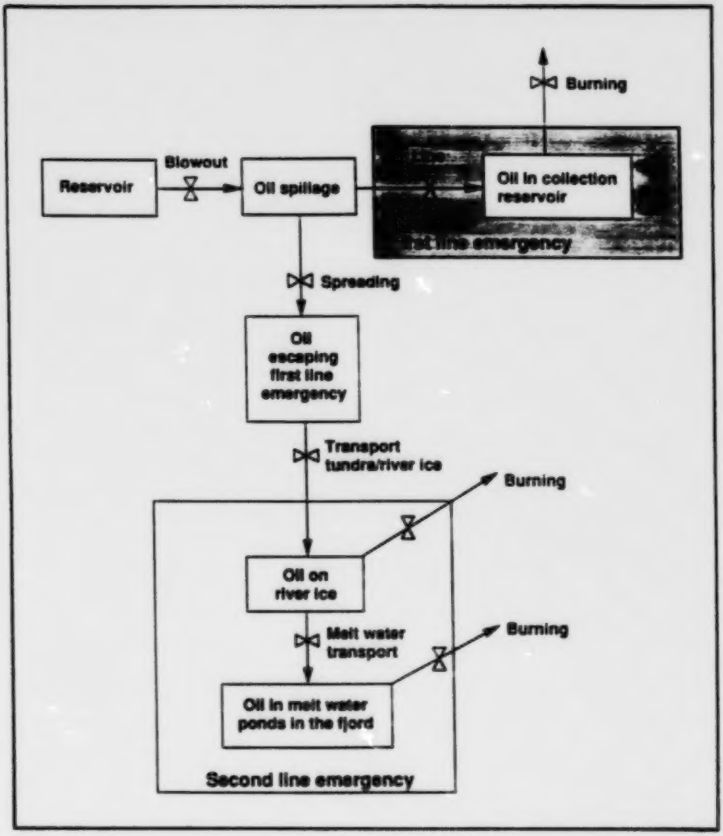
Burning
Reservoir
Blowout
Oil spillage
Oil in collection reservoir
First line emergency
Spreading
Oil escaping first line emergency
Transport tundra/river ice
Burning
Oil on river ice
Melt water transport
Burning
Oil in melt water ponds in the fjord
Second line emergency

Figure 2. Outline of the total oil spill contingency at the Reindalen 1 drilling as designed for a blow-out situation. The outline shows the relation between the frontline and the secondary contingeny, and emphazisis the position of burning, either in containments or in situ.

If the oil escapes the collection wall in winter, it will spread along the frozen river. In-situ burning is the major mitigation technique, if it is not possible to clean-up the oil and bring it inside the frontline contingency area. If oil escapes the frontline, ad hoc walls should be constructed downstream of the frontline to restrict spreading, and if necessary work as containments for **in-situ** burning. The main problem with the secondary contingency is assumed to be during the spring thaw, when water in the river will enhance spreading along the river, and into overflown areas. The river has its outlet in the Van Mijenfjorden. The fjord ice drifts out of the fjord in late June or early July. The presence of ice will contain the oil between the fjord ice layer and the ice foot. If oil from a blow-out has escaped the frontline contingency, and has not been dealt with before melting, there will be some weeks available for burning. A Helitorch is kept near the drilling site to ignite this oil.

All the fuel storage tanks were located collection walls made of ice with the capacity to keep the total volume of the oil if a spill should occur. The spill oil would be transported to the burning tanks described above, and ignited.

Equipment for the ignition of the oil was kept in a special container together with sorbents etc. which were also an important integrated part of the total contingency measures. All vehicles taking part in the transport to and from the drill site also carried specially designated equipment for the ignition of any accidental spill, as well as sorbents if ignition proved to be unsuccessful.

From experimental results to practical methods.

Implementation of experimental results into a contingency plan can be problematic. This issue was given significant attention by Norsk Hydro during the Reindalen 1 drilling. To assure that the recommended methods would be of practical use if accidental pollution should occur, several efforts were initiated:

> The drilling and transport crew were all trained theoretically and practically in oil spill contingency, and especially in the ignition of oil/snow mixtures.
>
> The contingency plan was published both in Norwegian and English to avoid any language problems, since both Norwegian and foreign crews took part in the operation.
>
> A short version of the oil spill contingency plan was published, and handed the crew and the authorities involved in oil spill contingency.

This pocket sized manual also contained practical hints in ignition techniques, as well as some background on the spreading of oil in snow, which is essential for the evaluation of the spill situation. Possible oil spill scenarios are described in flow sheets together with appropriate responses. Figure 3 presents an example of the flow sheet for the ignition of oil/snow mixtures, as it is presented in the manual (SINTEF 1991).

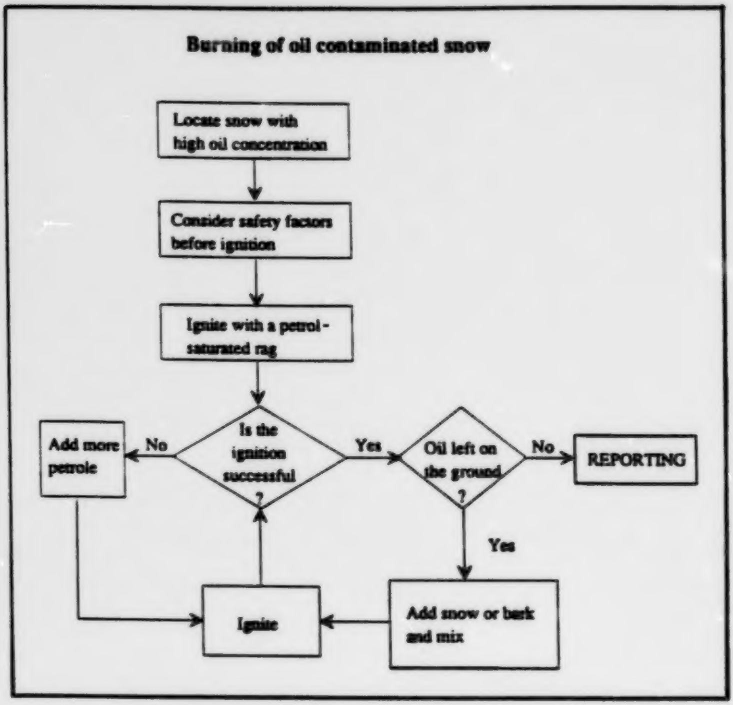
Burning of oil contaminated snow
Locate snow with high oil concentration
Consider safety factors before ignition
Ignite with a petrol-saturated rag
Is the ignition successful ?
No
Add more petrole
Yes
Oil left on the ground ?
No
REPORTING
Yes
Add snow or bark and mix
Ignite

Figure 3. **MANUAL FOR TREATMENT AND CLEAN-UP OF OIL SPILLS. Reindalen 1.** Flow sheet presentation of the procedures to be followed when oil/snow mixtures are to be ignited.

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OPERATIONAL EXAMPLES OF IN-SITU BURNING: LESSONS FROM THE BURNING OF TWO RECENT DIESEL SPILLS ON THE B.C.COAST

by

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ABSTRACT

The future success of in-situ burning will require a series of effective operational burns in addition to continued experimentation to improve technique. Thus, two case histories based on spill reports and the recollection of those in attendance are described with reference to strategy, countermeasures options, feasibility, effectiveness, resource protection, government regulation, property damage and safety. Both spills had important similarities: the product was diesel, operations were logging, locations were remote, and spill containment and recovery capacity nearby was limited. Differences were also significant: in one, containment was on the water behind boomsticks; in the other, a trench close to shore. In both cases though government agencies were notified, neither was subjected to a formal review process. The paper recommends that burn plan forms (checklist) be part of contingency plans in order to facilitate the approvals process and the safe and environmentally responsible burning of fuel spills.

INTRODUCTION

In a recent tabulation of historical burns and studies, there were only nine cited operational instances of burning to deal with a spill (Fingas and Laroche, 1991). The remaining seventeen examples were experimental spills, or in one case the analysis of a series of experiments. It is likely that the nine operational burns represent a fairly complete listing for spills classified as large or catastrophic; in contrast, burning at small and medium spills may have occurred but was accompanied by limited or very local documentation and thereby be virtually unknown. If there are safe and operationally effective opportunities for burning, such opportunities must be exploited, and the results documented. The two case histories described here provide such documentation. It must be pointed out that systematic measurements which accompany experimental burns were not attempted with these. As well, they are entirely based on the recollections of those in attendance.

SETTING

Both spills occurred at logging camps in remote parts of the British Columbia coast. There are large numbers of such camps, active ones number in the hundreds and at most there are substantial diesel fuel, gas, and other petroleum products in storage. At one logging division, fuel storage capacity at the sixteen separate operations (camps) amounted to 1,135,000 L of diesel, 215,000 L of gas, and 85,000 L of other petroleum based products. Cumulatively, there is a significant risk of spills from these facilities on the B.C. Coast. Moreover, because of their isolation and the limited amount of recovery equipment on site, most of what is accidently released is lost. Attempts have been made at least at the planning stage to airlift equipment to spill sites, but flying conditions vary and are frequently below minimum standards during the winter season. The boomsticks that are available at each camp can provide short term containment at best.

ST. VINCENT'S BAY SPILL, JANUARY, 1988

Incident Details: Over the Christmas period, 1987-1988, an estimated 9,000 L of diesel fuel leaked out of a mobile storage tank at a logging camp. The camp was situated along the shore of a West Coast inlet. The distribution of the storage tank, camp buildings, countermeasures activities, and shoreline are shown in Figure 1.

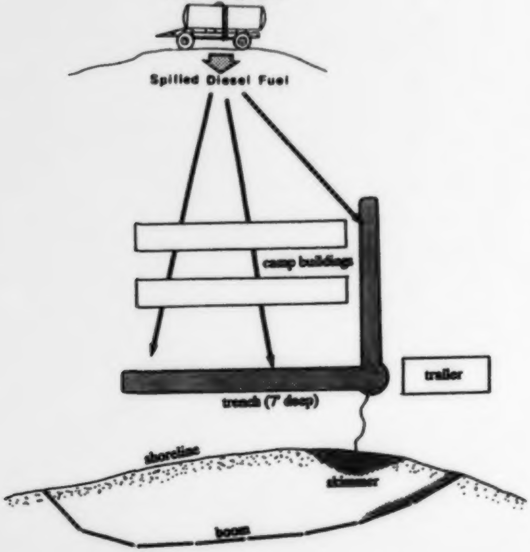

Figure 1 *Approximate location of storage tank, camp buildings and trailer, countermeasures activities, and shoreline, St. Vincent's Bay spill, January, 1988*

The ground was frozen when camp staff returned after the New Year and the spill was not immediately noticed. On January 8, approximately two days after re-opening camp, with the arrival of warmer, wet weather diesel fuel was seen leaching out of the ground, travelling along the inclined slope to the water line, and creating a slick in the bay. Company staff at division headquarters were immediately notified, as well as government agencies. They in turn loaded a small disc skimmer from their own facilities plus several hundred feet of boom from the nearby petroleum cooperative and arrived at the site quickly.

Containment/collection: While this response was being mobilized, the logging company moved one of its large backhoes to the spill site where it quickly excavated a trench 50' long, 7' deep and 3.5' wide with a deeper pit at one end to intercept the spilled fuel. This was successful, and several hours later an estimated 3"-5" of diesel had collected in the trench. With the arrival of the equipment in the late morning, the boom and skimmer were deployed in the bay. A hose from the skimmer was directed into the trench. Very little fuel was collected in this way, probably owing to the fact the slicks in the bay were so thin.

Ignition: The intention of the operator appears to have been to burn any diesel which could be recovered. This explains why the hose from the skimmer was directed back into the trench. At no time was a skimmer placed in the trench to recover the lost product to storage or disposal. Several issues were considered by senior staff and a federal government official:

i) feasibility of burning seemed favourable, particularly in view of successful collection of diesel in the trench;

ii) safety and property damage considerations appeared to be met by excavating a deeper pit at one end of the trench (Figure 1), and by placing a mound of fill between the pit and the rest of the trench to limit the extent of individual burns.

iii) government agencies had been immediately notified, but no formal approval for burning appears to have been attempted.

iv) countermeasures options other than burning may have seemed limited from the operator's perspective.

Over the course of January 8 and 9, the collected diesel was ignited on several occasions. In each case, a handful of straw was ignited and thrown into the trench. In spite of the temperature (est. 6°C), overcast conditions, and a light rain, the diesel quickly ignited. Two factors above all others probably explain the successful ignition. First, according to observers several inches of diesel had already collected. Second, lying in a trench the fumes from the evaporating diesel fuel would have concentrated to a considerable and potentially dangerous extent. This may not have been appreciated by observers at the surface exposed to local circulation. No doubt, the high concentration of fumes assisted the ignition process.

Burn Phase: In all but one case the diesel burnt for several minutes before dying out. In that one case, within less than one minute, the fire jumped the earth mound and spread down the trench, was generating more heat than anticipated, and was threatening the nearby trailer. The contractor on scene recognizing this risk quickly restarted the backhoe, and with sideways sweeps of the bucket was able to backfill part of the trench and extinguish the fire. The elapsed time from ignition to extinguishing the fire was no more than five minutes. There was considerable external damage to the trailer.

On the following day (January 9), the collected fuel was burned safely on three or four occasions. Small amounts of diesel continued to migrate through the beach substrate, some of it collecting in the trench. Here it was burned off on several occasions during the next two weeks until the flow became negligible and the incident was terminated.

RIVERS INLET SPILL, NOVEMBER, 1990

Incident Details: During the morning of November 23, 1990 staff at the logging operation at Rivers Inlet reported a series of slides in the steep drainage immediately above their log dump and fuel storage area. Boulders hit the fuel tanks, and a leak was suspected, but the continuing heavy rains and risk of further slides precluded an examination of the damage. As a precaution, several hundred feet of boom sticks were deployed in the water around the storage facility. Short lengths of absorbent boom were secured in the gaps between individual sticks. The configuration of the storage tanks, shorelines and the boomed area are shown in Figure 2.

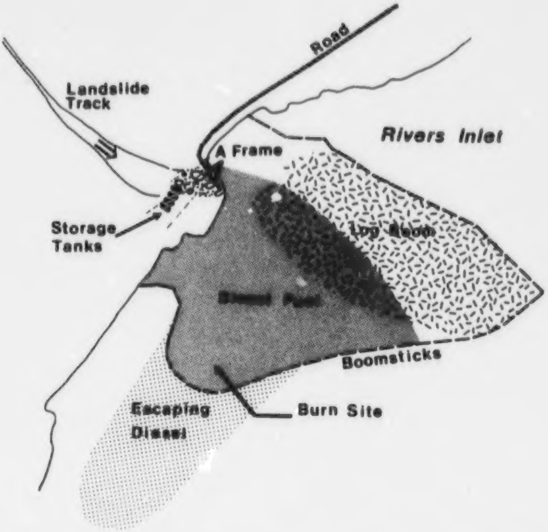

Figure 2 *Location of tank farm, boomsticks, log boom, shoreline and burning site, Rivers Inlet spill, November, 1990.*

The following morning (November 24), staff and contractors approaching the site noticed diesel contained in the boomed area and several of the tanks punctured. Later estimates indicated the following losses: 68,000 L diesel, 15,000 L gas, and 2,000 L stove oil. Conditions at the time were calm (<5 km E), partially clear.

Containment/collection: Appropriate notifications and requests for assistance were made immediately. Containment using boomsticks was partially successful, but some fuel was leaking out at the seaward end of the boom. There was an ebbing tide creating sufficient current to weaken containment. For recovery, the camp had only several bales of absorbent pads. Neighbouring camps (10 - 100 km distant) had similar modest inventories, as determined during the preparation of the operations' contingency plan: adequate for a few litres, but not 85,000. Arrangements were being made to fly in a disc or weir skimmer from Vancouver Island, but that was several hours away. Another concern was the probable increase in wind velocity.

Ignition: Given the continued losses of diesel fuel out of the boom, and the temporary inability to recover the contained diesel at any significant pace, consideration was given to burning. The following issues were reviewed by senior staff and a federal government official:

i) property damage: risk to the existing tank farm and nearby log boom without adequate separation from the contained fuel;

ii) environmental approval;

iii) potential environmental damage under a variety of scenarios: the worst being losing containment and the fuel under deteriorating weather;

iv) safety of spill response personnel;

v) inadequacy of alternative countermeasures.

The decision was made to proceed with the burn.

The ends of the boom were released from their original placement and redeployed so as to provide separation between the collected fuel,and the tank farm and log booms. A recent helicopter survey had shown significant patches of uncontaminated surface water between these areas, thus supporting the notion that a safe burn could occur without flashback.

Ignition took place over a period of several minutes, starting at approximately 1415 hours. A fuel-soaked absorbent pad was reported to have been thrown from one of the two attending dozer boats onto the collected fuel. Ignition was slow, and the process was repeated. Whether gasoline was used to speed up this process has not been confirmed. After fifteen minutes, a substantial burn was taking place (Figure 3).

Burn Phase: Neither the precise timing of the burn, nor its dimensions were recorded at the time. Recollections indicate that the period from the initial attempts at ignition to the fire going out approximated 30 minutes. Burn dimensions have been estimated using the 16' dozer boats as a point of reference. This indicates a spill diameter of less than 40'. Fuel thickness was not determined. On the basis of this limited information, it would appear that the burn consumed no more than 10,000 L. While modest in relation to the total released from the various tank ruptures, the burn was a success and provides a model for future spills in remote locations.

CONSIDERATIONS

Burning is a highly unique approach to dealing with spilled oil or petroleum products. Because it may be difficult to control, burning is accompanied by significant risks of personal injury, property damage, and air pollution not associated with other countermeasures alternatives. The various

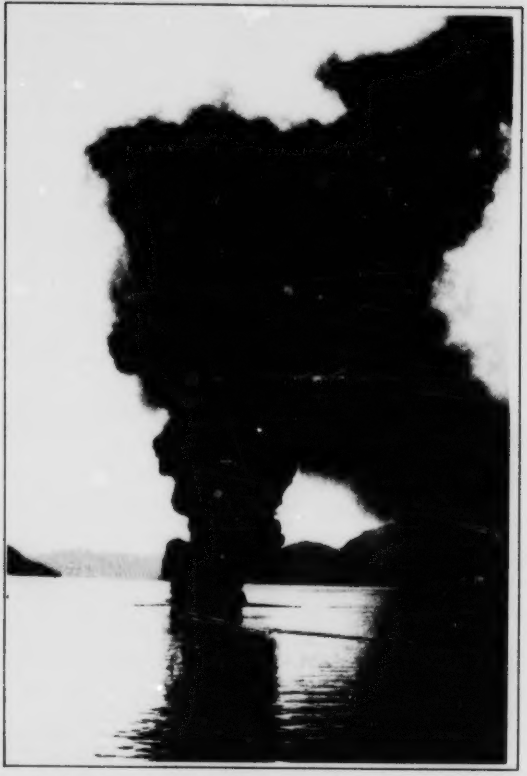

Figure 3 In-situ burning of spilled diesel fuel, Rivers Inlet November, 1990.

technologies which comprise mechanical removal involve other risks. Mechanical means have tended to be slow and inefficient, thereby extending both the duration and areal extent of contamination. In many cases, such as the two described here, booming and mechanical removal equipment are available in limited supply, and therefore burning should be actively considered at the start.

To do so in a conscious fashion and meet statutory and regulatory requirements, responsible operators will have to be supplied with technical assistance, preferably beforehand. This assistance would best be in the form of a checklist, which upon completion would greatly facilitate the authorizing of a proposed in-situ burn. In British Columbia, spilled diesel is a special waste (D. Walton, B.C. Ministry of Environment, pers. comm.), but Section 52 of the Special Waste Regulation (Special wastes from accidental spills) empowers "a manager or the director [to] exempt a person from any of the requirements of this regulation in relation to special wastes originating from response to accidental spills of dangerous goods". In the absence of explicit guidance to such managers, there is considerable advantage to both the regulator and the spillor if an in-situ burning checklist is completed. A logical corollary of this point is that for appropriate facilities contingency plans should include this type of checklist.

An in-situ burning checklist prepared by the Alaska Regional Response Team in December, 1990 provides the elements of a useful model. In particular, its requirements for a burning plan cover the essential safety and environmental issues for the types of remote fuel storage facilities referred to in this paper. Among the twenty points in this plan, the following information requirements seem most germane to such operations:

- proposed burning location in relation to source, nearest ignitable slicks, and nearest land;
- location and type of nearest human habitation;
- proposed ignition method;
- method of oil containment;
- estimated smoke plume trajectory;
- proposed procedures to notify downwind residents.

At the conclusion of a burn, the spillor remains responsible for cleaning up the residue and the unburnt oil.

This paper concludes that in-situ burning is a feasible and environmentally responsible option for dealing with fuel spills, particularly in isolated locations. In view of the countermeasures options, it is a technique which warrants cautious promotion. This assumes the unknowns associated with burning can be addressed by the spillor completing a burn plan, which in consultation with regulators, should be straight forward to fill out and implement.

ACKNOWLEDGEMENTS

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Smoke Emission from Burning Crude Oil

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ABSTRACT

Research has shown that burning can be an effective means to remove oil from the surface of the water after a spill. Previous research has focused on laboratory studies of combustion products from oil pool fires less than 1 meter in diameter. This paper describes instrument packages developed to determine the amount of various combustion products emitted from large (15 m x 15 m) crude oil pool fires. Based on samples drawn directly from the smoke plume immediately downstream of the flame, burning a mixture of Arabian light and Murban crude oils in a 2.7 m x 2.7 m pan produces a smoke yield of 0.15. Preliminary results from burning Louisiana crude in a 6 m x 6 m pan indicate a similar 0.14 of the crude oil is converted to smoke in the combustion process. The increase in burning rate and smoke production with increasing fire size is discussed. Progress is reported on new calculation methods for smoke dispersion and downwind deposition of particulate. Results of example calculations are presented.

INTRODUCTION

Response to oil spills includes consideration of oil containment, recovery, disposal and the logistics of delivering adequate response equipment quickly to the spill site. The use of burning as an oil spill response method is attractive, particularly in remote areas. Burning requires a minimum of equipment, and because the oil is gasified during combustion, the need for physical collection, storage, and transport of recovered product is reduced to the few percent of the original spill volume that remains as residue after burning.

Concerns regarding the safety of burning and the impact of the smoke on the public health have hampered the use of burning as an oil spill response method.

Burning oil spills produces a visible smoke plume containing smoke particulate and other products of combustion. The public health concerns relate to the chemical content of the smoke plume and downwind deposition of particulate. Safety concerns have been raised regarding the effects of heat and thermal radiation from large fires on personnel and equipment. These concerns are being addressed both through measurements and predictions of effects of oil spill burning in a research program conducted by the U.S. National Institute of Standards and Technology (NIST) and sponsored by U.S. Minerals Management Service (MMS), U.S. Coast Guard (USCG) and the American Petroleum Institute (API).

BACKGROUND

In this six year research program, specialized large laboratory scale fire facilities at NIST have been used to investigate the fire dynamics and chemistry of the oil spill burning process. These studies have provided new quantitative information about the crude oil burning process including smoke particulate characteristics, polycyclic aromatic hydrocarbon (PAH) content, smoke plume trajectory and particulate settling. The results of this research have been presented previously [1-6].

The large accidental spill of crude oil from the tanker Exxon Valdez in Prince William Sound, Alaska focused national attention on oil spill response technology. In cooperation with a team of interested parties from industry and government, planning has begun for operational tests of burning on an experimental oil spill at sea in 1991. In preparation for these tests, the NIST research program is developing means to measure the burning characteristics of these large fires. To accomplish this task, NIST has developed methods and equipment for field measurement of many of the quantities used to evaluate crude oil combustion in the laboratory [5].

This paper contains results of measurements using the methods and equipment developed to evaluate the burning of crude oil. These measurements involved the use of fire testing facilities in both the United States and Japan. To assist in preparations for the offshore burns there has been an emphasis on understanding the effects of the area and quantity of fuel being burned (fire scale) on measured quantities. In this same regard, progress is reported on calculation methods capable of predicting the trajectory and settling of particulate from smoke plumes produced by burns of a size expected in an actual spill response which are larger than burns which can be reasonably conducted as experiments.

FACILITIES

The development and testing of new measurement equipment and techniques to evaluate crude oil combustion in offshore field tests of in-situ burning involved the use of four different facilities. Two of these facilities are large fire test laboratories and the other two are outdoor liquid fuel burn pans.

Initial laboratory measurements of crude oil burning characteristics were performed in the fire test facility at NIST. Basic measurements of the combustion process were performed by burning crude oil in 0.4 m and 0.6 m diameter pools and collecting the combustion products in a specially constructed and instrumented exhaust hood system shown in Figure 1. Samples drawn from the exhaust hood duct were used to quantify the amount of each major combustion product generated per kilogram of crude oil burned, the chemical composition of the smoke including polycyclic aromatic hydrocarbon (PAH) content, the size distribution of smoke particles, and the oxygen consumed in the combustion process. Oxygen consumption rate was used to calculate the heat release rate of the fire, which is the primary quantity used to characterize burning intensity. To further characterize the combustion process, additional instrumentation was used to measure radiant heat flux from the flame and mass loss rate of the burning fuel [5].

The relatively small, 0.6 m diameter, fires provide a good means of measuring fire characteristics under controlled conditions but are too small to provide a adequate test of measurement equipment being developed for field use. Through the cooperation of the Fire Research Institute (FRI) in Tokyo, Japan, joint studies of crude oil burning were conducted. FRI maintains a fire test facility in which crude oil pools up to 3 m in diameter are burned with all of the combustion products collected in a large hood system. Figure 2 shows a crude oil fire burning in the 24 m x 24 m x 20 m high test hall. This facility provided means to test the sampling equipment developed for field use under controlled laboratory conditions.

As part of the fire fighter training program at the U.S. Navy Fire fighter training facility in Norfolk, Virginia, 15 m diameter fuel oil fires are burned and extinguished. These fires were used as burns of opportunity to refine the techniques for instrument transport and positioning in an outdoor wind blown fire plume. Figure 3 shows a tethered blimp used to carry an instrument package into the plume from a test fire at the facility.

The final stage of preparation for the offshore burns involved the use of fully operational measurement methods in meso-scale crude oil burns up to 15 m square. In cooperation with the U. S. Coast Guard Fire and Safety Test Detachment in Mobile, Alabama, burns have been conducted in a new burn pan facility on Little Sand Island in Mobile Bay. The 15 m square and 0.6 m deep pan, shown in figure 4, was surrounded by a water filled channel designed to

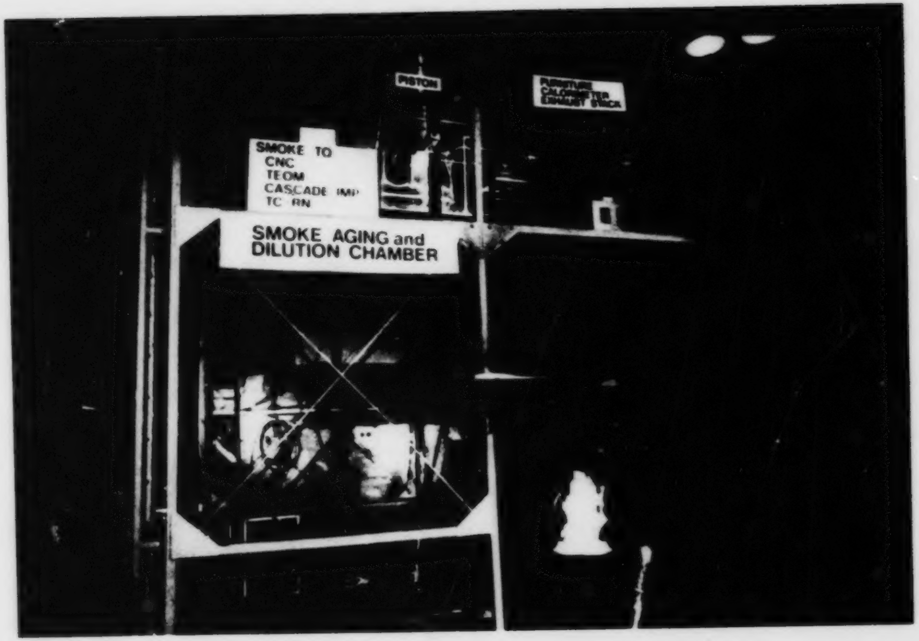
PISTON
FURNITURE CALORIMETER EXHAUST STACK
SMOKE TO
CNC
TEOM
CASCADE IMP
TC RN
SMOKE AGING and DILUTION CHAMBER

Figure 1 NIST Fire Test Laboratory, Gaithersburg, Maryland

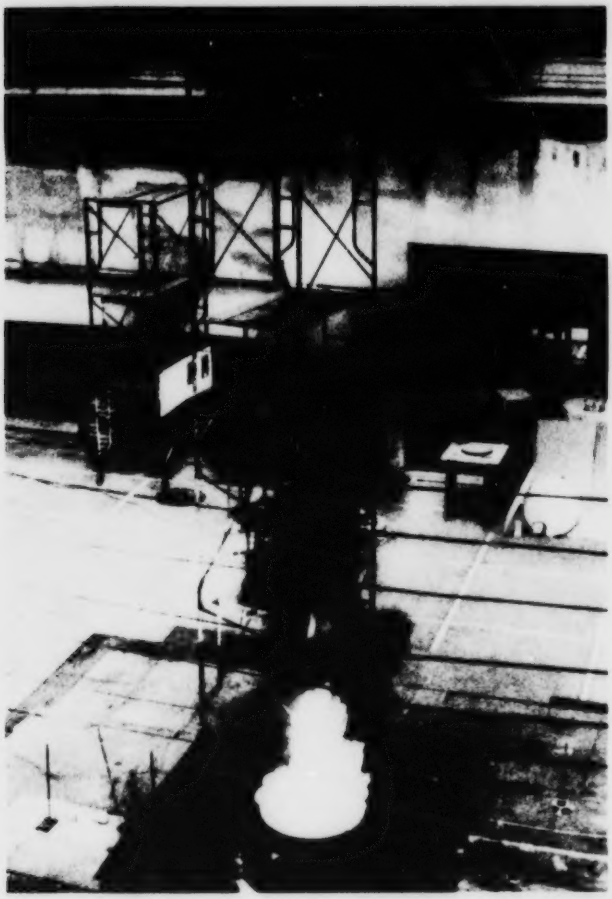

Figure 2 Fire Test Laboratory at Fire Research Institute, Tokyo, Japan

Figure 3 Navy's Farrier Firefighting Facility in Norfolk, Virginia

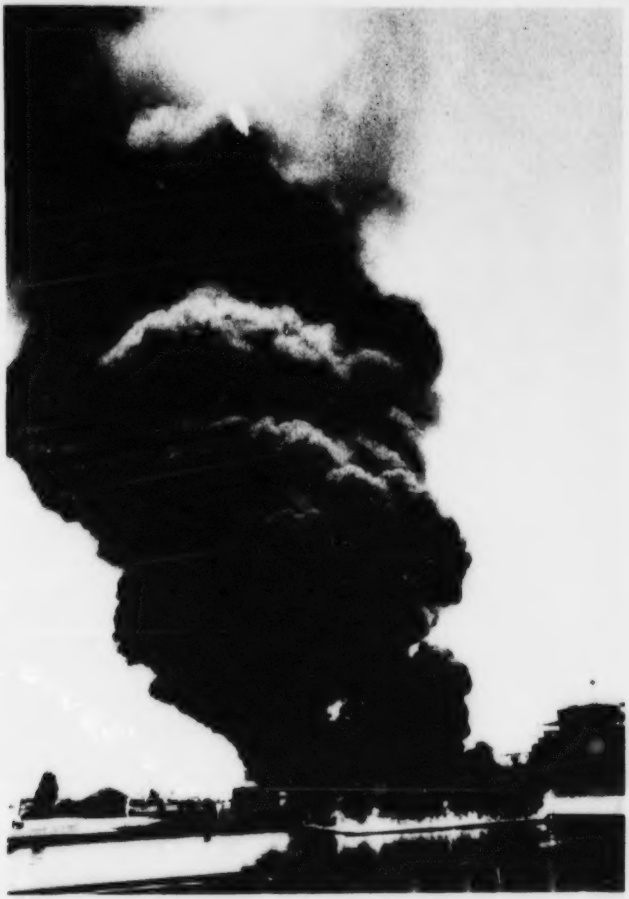

Figure 4 USCG Fire and Safety Test Detachment burn facility, Mobile, Alabama

protect the pan. In addition to the airborne measurements in the smoke plume, extensive ground measurement equipment was used to characterize the fire thermal radiation field, chemical and particulate species present, and local weather conditions.

BURNING RATE

The controlling mechanisms for the burning are presented in the often cited review of the Blinov and Khudyakov studies by Hottel [7]. Pool fire studies generally seek to understand the burning rate, flame height, and thermal radiation emitted as a function of pool diameter [8]. Normally single component liquid fuel pool fires are studied. After an initial ignition transient, these fires achieve nearly steady burning conditions. Over the range from normal laboratory experiments (order 0.1 m diameter) to field scale (order 10 m) there is a strong increase in burning rate per unit area. This reflects a change from convection dominated heating of the fuel at 0.1 m diameter to radiative dominated heating at the large fire diameters. The dominance of thermal radiation from the turbulent flames and the nearly equal heat of vaporization for the hydrocarbon fuels measured results in a nearly the same constant burning velocity (fuel surface regression rate) for all of the fuels in large diameter pools [7].

The study of crude oil combustion on water is complicated by two factors. One is that the oil is being burned in a layer floating on water. The other is that crude oil is a blend of many hydrocarbons with a wide range of boiling points the majority of which are at greater temperatures than the boiling point of water. For example, distillation measurements of South Louisiana crude oil show that 90 percent of the compounds in the oil have boiling points above 100°C [9]. During burning the surface of the crude oil maintains a temperature of around 300°C. As the fuel is consumed, heat transferred through the fuel to the water below can boil the water. This effect of "thin layer boilover" has been observed in laboratory crude oil pool fires with nominally 1 meter diameters [1]. The result of this boiling of the supporting water level is to agitate the fuel layer with both fuel and water droplets being sprayed into the flame, substantially increasing the burning rate of the fire [1,2]. Measurements of particulate formed during this intensive burning period have indicated that smoke production per kilogram of fuel consumed is reduced compared to burning prior to the "thin layer boilover [3]." The role of boilover in crude oil combustion at large scale is unclear at this time. It is being studied as part of this research through cooperative experiments with the Fire Research Institute in Japan [10] and through analysis [11].

Ignoring the complications of fuel distillation and boilover phenomena, the available data from burning of crude oil pool fires, figure 5 [12], suggest that burning velocities are nearly constant for pool diameters in the range of 5 m to 30 m. Based on these data, the pan built for the meso-scale crude oil fire tests to be conducted in Mobile, Alabama was designed to accommodate pool

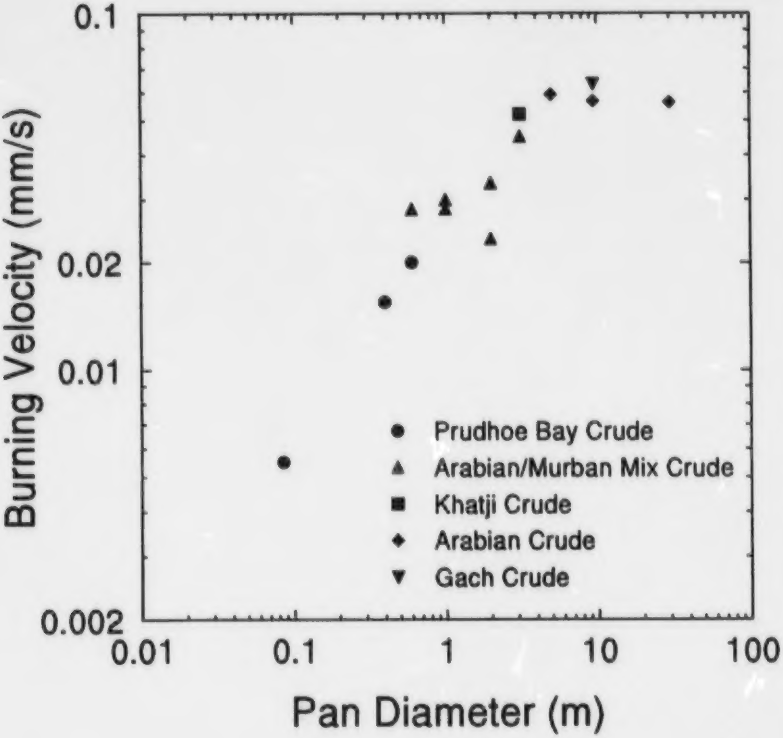

Figure 5 Crude oil fire burning velocity [10]

diameters up to 15 m. This was thought to be large enough to assure that the resulting fuel consumption per unit area would be the same as in the future larger burning area offshore tests.

In preliminary test burns in a 6 m x 6 m corner of the 15 m x 15 m pan on Little Sand Island in Mobile Bay, a 45 mm deep layer of Louisiana crude oil on bay water was consumed in 812 seconds. This equates to an average burning velocity of 0.055 mm/s. This datum agrees with other crude oil burning rates plotted in figure 5. Observations during the burn indicated that "thin layer boilover" occurred. The effect of boilover on the fuel consumption rate in large diameter pool fires has not been evaluated. Measurements to evaluate burning during "thin layer boilover" are being planned for future meso-scale experiments.

SMOKE YIELD MEASUREMENT

Methods to measure the smoke production from liquid pool fires have been evaluated in laboratory tests [1]. Smoke yield, the mass of smoke particulate produced from burning a unit mass of fuel, can be determined using the carbon balance method in both laboratory and field experiments . Smoke yield by the carbon balance method is the product of the measured fraction of carbon in the fuel and the ratio of the measured carbon in the form of smoke particulate to the measured total carbon in the combustion products including particulate, CO_2 and CO.

The carbon balance method is the only known method for determination of smoke yield in field tests because it does not require measurement or knowledge of the total combustion product flow. With regard to smoke yield measurements, field burns differ from laboratory experiments in that the combustion products are not collected into an exhaust stack, but are dispersed in a buoyant flow from the combustion zone. The application of the carbon balance method to smoke yield measurements in the field can be made with the assumption that in the region of the plume from which samples are drawn, both the smoke particulate and gaseous combustion products have been transported together from the combustion zone and their concentrations have been equally diluted by entrained air.

Smoke Sampling Package

A self-powered sampling package that is capable of being switched on and off by remote control was constructed to measure smoke yield in plumes from large crude oil fires. The package is shown in Figure 6 and components are diagrammed in Figure 7. At the heart of this system is the battery powered pump. This pump provides a constant volumetric air flow into the system by automatically compensating for the increase in pressure drop across the filter as it collects sample. Although the pump flow can be varied to adjust for different sampling durations and expected smoke particulate concentrations, the pump

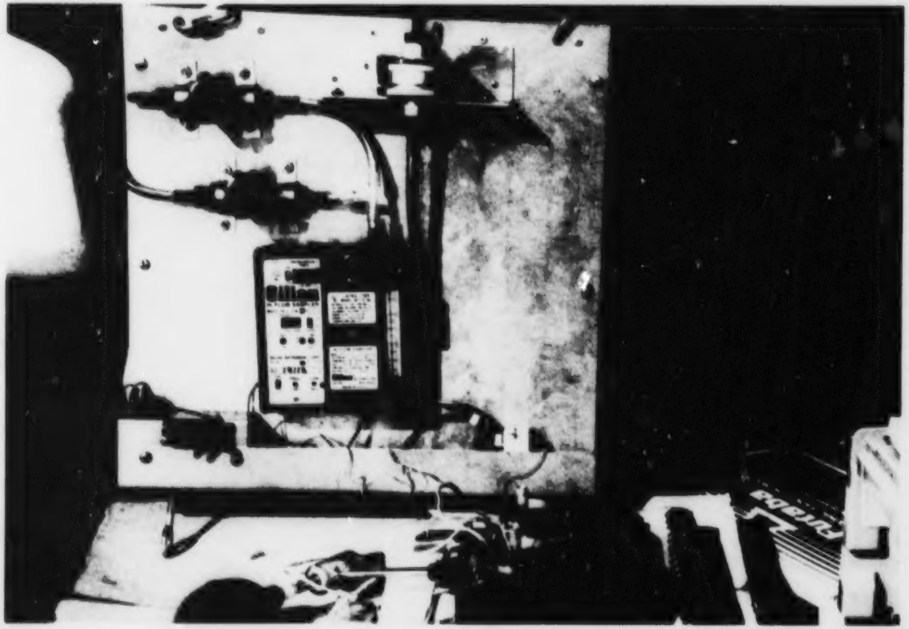

Figure 6 Assembled smoke sampling package

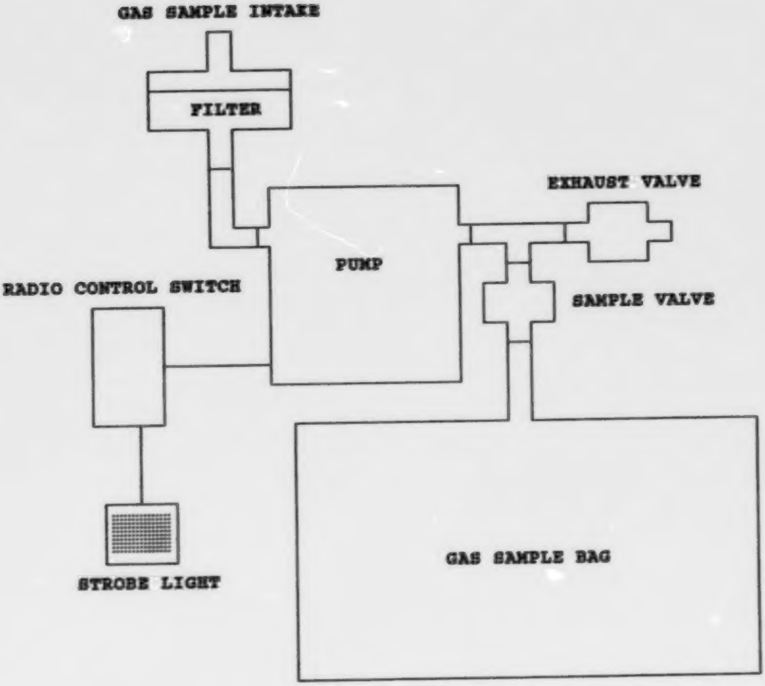
GAS SAMPLE INTAKE
FILTER
EXHAUST VALVE
PUMP
RADIO CONTROL SWITCH
SAMPLE VALVE
STROBE LIGHT
GAS SAMPLE BAG

Figure 7 Diagram of smoke sampling package components.

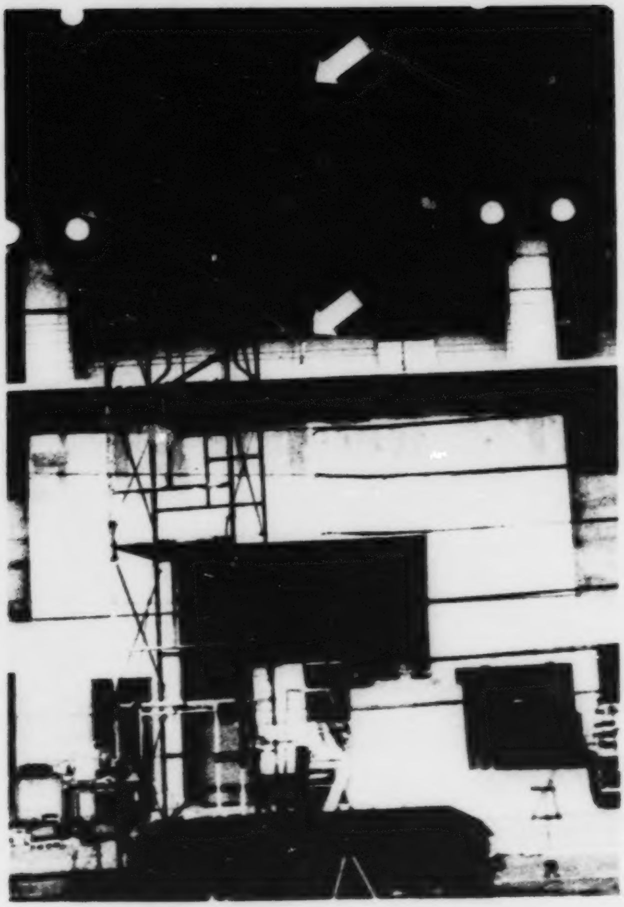

Figure 8 Picture of relative location of high temperature smoke probe and of the portable smoke collector in FRI experiments.

generally provides a flow of 67 cm^3/s. In addition, a set of micrometer adjusted flow control valves are used to split and meter the exhaust gas flow from the sample flow to a 5 liter sample collection bag. A radio controlled switch provides means for starting and stopping the pump remotely as the sample package is carried into and removed from the fire plume. The sample package is designed to be suspended below a blimp which is stationed well above the plume in clear air such that the package can be brought into the plume flow without subjecting the blimp to the heat and turbulence of the fire plume. Since the package is generally positioned in the plume tens of meters above the ground, the pump switch also operates a high intensity strobe light which provides a visual indication that the smoke yield system is sampling. This strobe also provides a visual marker for accurately timing the duration of the sampling period.

Equipment Evaluation

To evaluate the performance of this new portable smoke sampling equipment, relative to an existing laboratory system for high temperature smoke sampling, both sets of equipment were used to sample smoke from 1 and 3.1 meter diameter pool fires at the Fire Research Institute in Japan. Tests were performed with a mixture of Arabian light and Murban crude oils in a 1 meter diameter circular pan and in a square pan with 2.7 m sides. The effective diameter of the square pan is defined as the diameter of a circle (3.1 m) with area equal to the square pan. In these experiments the fuel layer was 0.024 m deep floating on a 0.2 m layer of water for the 1 meter pool and .027 m deep layer floating on a 0.45 m layer of water for the 3.1 m pool. In addition to evaluating the portable sampling equipment, these experiments provided an opportunity to collect data on the effect of pan diameter on smoke yield and agglomerate structure.

Figure 8 illustrates the location of the two sampling sites in the FRI laboratory; the probe for the high temperature smoke collection system was located 4 m above the pan and the new portable smoke collector 6.5 m above the pan. In the 1 meter diameter crude oil pool burns, the flame reached a maximum height of about 3 m as shown in Figure 2. The gas temperature at the high temperature probe was about 80°C with ± 20°C variations and that of the portable sampler was about 40°C as illustrated in Figure 9. The temperature variation results in part from the turbulent nature of the plume and in part from the tendency of the plume to bend in response to the wind outside the building. The pronounced peak during the later stage for the high temperature probe is a result of "thin layer boilover" causing an enhanced burning rate [10]. The portable probe was removed from the high temperature plume before the onset of this boilover.

The smoke particulate drawn from the high temperature probe was collected on a thimble shaped fiberglass filter. A portion of the gases flowed through a silica gel moisture trap and then to CO and CO_2 nondispersive infrared analyzers. The low flow through the gas analyzers combined with the integrating effect of the volume of the desiccator and the instrument cell volume resulted in a 50 - 100 s

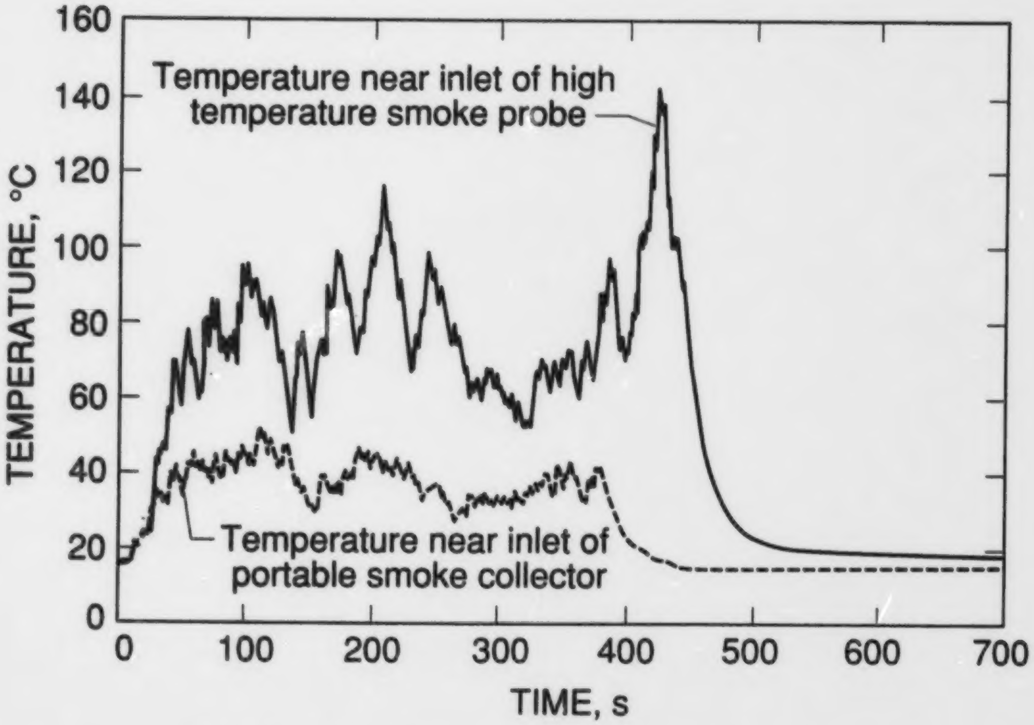

Figure 9 Temperature versus time near smoke collection inlets for a crude oil fire in a 1 meter diameter pool.

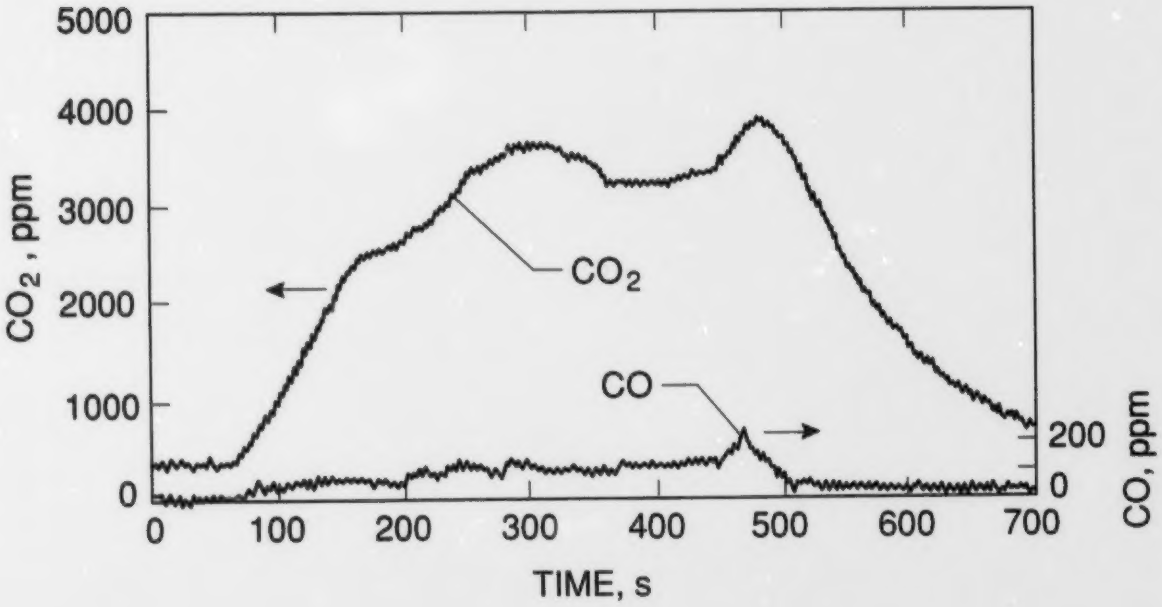

Figure 10 Volume concentration of CO_2 and CO versus time sampled by the high temperature smoke probe.

time delay in the concentration data. There is also a significant smoothing of the data as shown in Figure 10. The gas concentration curves are integrated to compute the average concentration over the test. From the mass of smoke collected on the filter, the carbon fraction of the fuel (.855), and the average gas concentrations, the smoke yield was determined using the carbon balance method [1,13].

The portable sampling equipment collected smoke on a polytetrafluoroethylene (PTFE) filter at a constant flow rate of 67 cm^3/s (4 liters/min). A small fraction of the flow, about 4 cm^3/s, was collected in a 5 liter sample collection bag for subsequent analysis by gas chromatography. From the concentration of the CO_2 and CO in the bag and the mass of smoke collected on the filter, the smoke yield was determined by the carbon balance in much the same way as with the high temperature smoke collector. The bag sample provides an integrated sample from the entire test, while the real time results of the high temperature require averaging over the time of the test. As the fire was ignited, the sampling pump was started and then immediately positioned above the fire by pulling on a wire drawn over a crane mounted hook. The portable sampler was removed from the smoke before boilover and the pump turned off.

Because of the much larger flames from the 3.1 m diameter crude oil pool fires, the high temperature collection probe was positioned in the stack and the portable sampler was positioned out of the smoke plume in the smoke layer, which filled the upper half of the facility. The stack temperature was about 110°C for the large fires. The temperature at the inlet of the portable collector was about 70°C.

As indicated in Table 1, the smoke yield obtained by the two different methods are comparable for the large fires with an average value of 0.148 for the portable and 0.149 for the high temperature collection probe. For the smaller fires, the results from the portable collector, 0.100 are significantly larger than the results obtained with the high temperature probe, 0.061. The measurement repeatability is about ± 10% as indicated in Table 1. One reason for the lower yield for the high temperature probe is the collection of smoke during boilover, which may have a lower smoke yield, while the portable smoke collector collects smoke only before boilover. Because of the large tare weight of the thimble filter, 1800 mg compared to the 250 mg PTFE filter, and the sensitivity of the thimble filter to moisture, we consider the results from the portable collector to be the more reliable.

These results indicate that the portable sampling device is capable of an accuracy on the order of 10-20%, assuming accurate gas analysis. The primary limitation is the accuracy of the flow control in an environment of variable temperature and pressure. Work is in progress to define the magnitude of these uncertainties for the range of conditions expected during plume sampling in the meso-scale experiments.

		Smoke Yield		
Test #	Pan Size, m	High Temp. Probe	Port. Sampler	Diameter of Spherule, μm
C-2	1		0.090	
C-3	1	0.065	0.109	
C-4	1	0.057	0.097	
C-5	1		0.103	0.060
Average of C-2 to C-5		0.061	0.100 ± 0.008	
C-6	3.1	0.133	0.148	0.15, 0.064[a]
C-7	3.1	0.153	0.160	
C-8	3.1	0.162	0.137	
Average of C-6 to C-8		0.149 ± 0.015	0.148 ± 0.011	

[a] The two sizes correspond to the larger and smaller primary sizes shown in Figure 13.

Table 1 Smoke Yield Measurements From Experiments at FRI

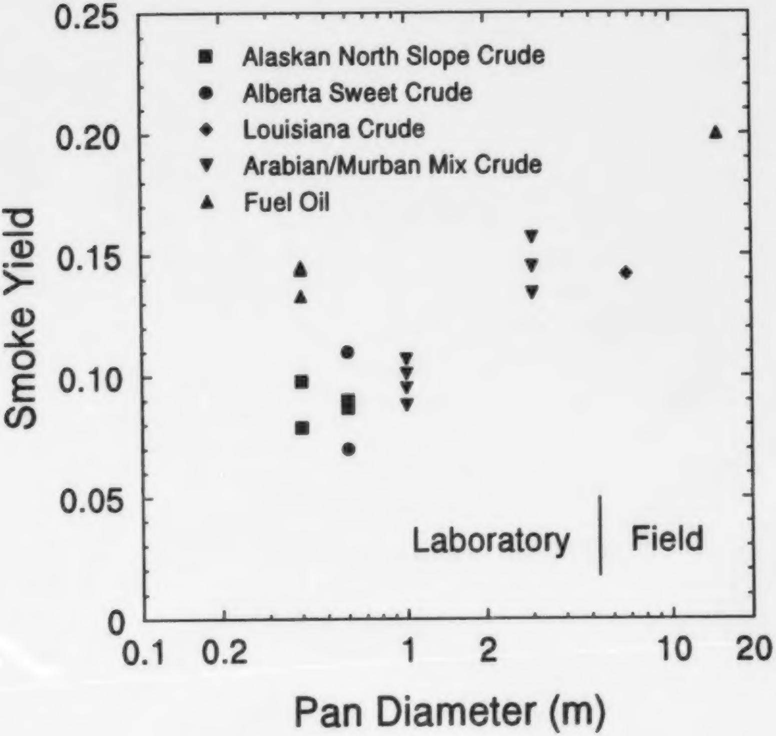

Figure 11 Smoke yield from oil pool fires.

Effect of Scale

As with burning rate, there is an effect of scale for smoke yield. Smoke yield for smaller laboratory fires appears to be less than for larger fires. As with burning rate the smoke yield is expected to become independent of pool fire diameter at large diameters. Figure 11 shows a compilation of smoke yield measurements from various crude oil burns in this research program. The data from several different facilities burning different fuels are divided into laboratory experiments which indicate fires conducted indoors and field experiments which are outdoors. As expected, smoke yield increases with increasing pool diameter. Burns of the mixed Arabian and Murban crude oils at the Fire Research Institute in Japan indicate a 50 percent increase in smoke yield from 0.1 for the 1 m diameter pool fires to 0.15 for the 3 m diameter. Field experiments at the Navy Fire Fighter Training facility in Norfolk, Virginia indicate that the fuel oil used there has a greater smoke yield (0.20) than any of the unrefined crude oils tested in both laboratory and field burns. Preliminary results indicate a 0.14 smoke yield in the new facility shakedown test at the USCG Fire and Safety Test Detachment in Mobile Alabama in which a 6 m x 6 m pool of Louisiana crude oil (6.8 m effective diameter) was burned. Based on these measurements, it is expected that in the offshore field tests a nominal 0.15 smoke yield can be expected from the large crude oil in-situ burn.

Smoke Particulate

Smoke samples were collected on carbon coated TEM grids (3-mm diameter, 0.13 mm thick, and 200 mesh copper) in the exhaust stack. Two grids were attached to a metal rod with double stick tape in such a way that only a small outer portion of the grid was in contact with the tape. The metal rod was inserted and removed from the stack three times for about five seconds each. One of the grids was then removed from the rod. The remaining grid on the rod was reinserted and removed from the furnace in a series of five second exposures until a particulate loading approximately five times that on the first grid had accumulated on it. The primary mechanism of particle deposition is thermophoretic resulting from the temperature gradient between the high gas temperature in the stack (about 110°C for the 3.1 m diameter pan) and the near ambient temperature of the grid attached to the metal rod. Thermophoretic collection has the advantage of being relatively insensitive to particle size so that a representative size distribution is collected. In the case of the 3.1 m pan diameter, TEM grids were also attached to the portable smoke collector being evaluated in the experiments.

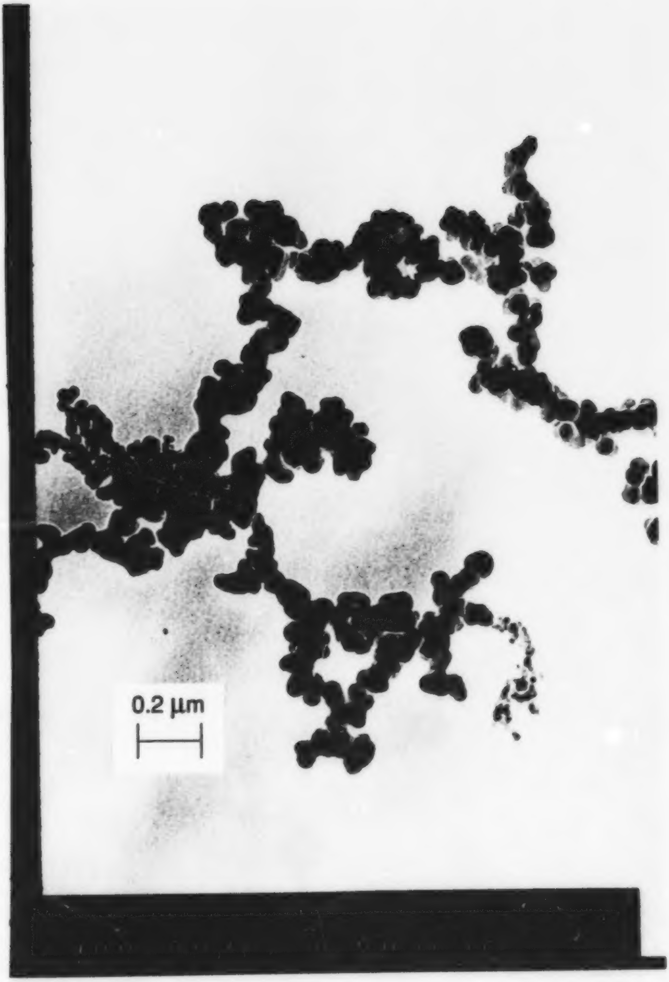

Figure 12 Electron micrograph of smoke agglomerate collected from a 1 m diameter pan diameter fire.

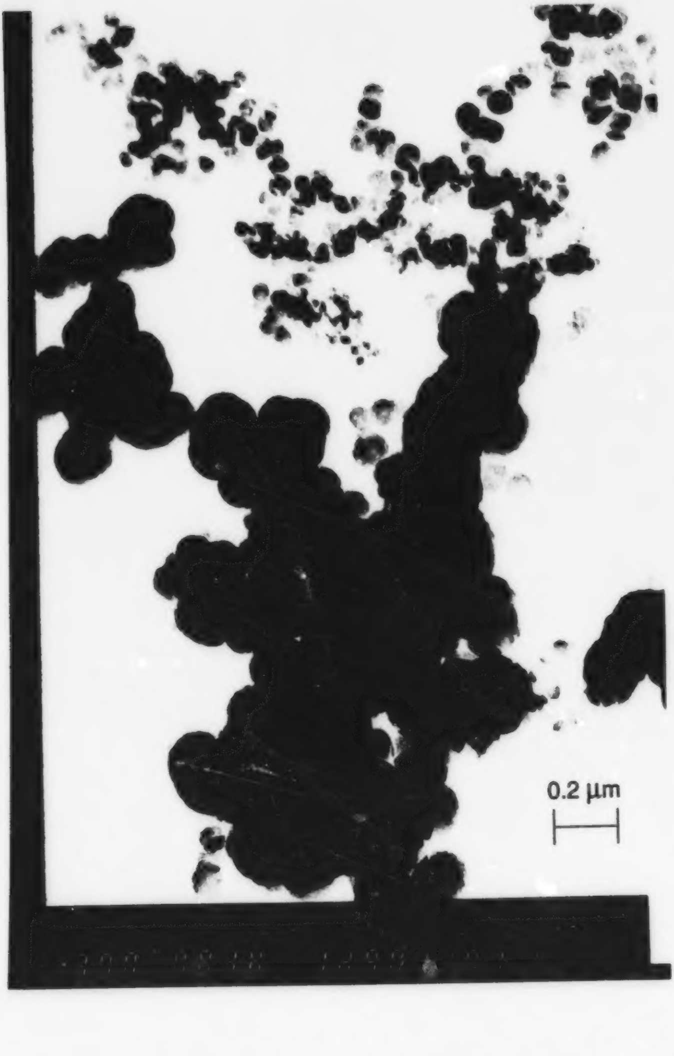

Figure 13 Electron micrograph of smoke agglomerate from collected from a 3.1 m diameter pan diameter fire.

The smoke samples were analyzed at Tokyo Science University using a Hitachi-H800[1] transmission electron microscope operating at 100 keV at a magnification of 30,000. Representative micrographs of the smoke agglomerates are illustrated in Figure 12 for the 1 m diameter pool fire and in Figure 13 for the 3.1 m pool fire. As seen from Figure 12, the primary spherule size is relatively uniform for the 1 m pool fire and a preliminary analysis based on sizing ten primary spherules gives an average diameter of 0.060 μm. For the larger pool fire, both large primary size spherules and smaller spheres are present on all of the ten micrographs from the analysis. From sizing 10 of the larger spheres and 10 of the smaller spherules from the micrograph shown in Figure 13, an average value of 0.15 μm is obtained for the larger and 0.064 μm for the smaller. The size of the smaller spherules from the 3.1 m diameter fire is close to the size observed for those produced in the 1 m diameter fire.

The increase in pool diameter and therefore size of the combustion zone leads to a population of primary particles significantly larger than seen at the smaller scale. The appearance of a distinctly larger spherule size suggests the possibility of a different growth mechanism. Perhaps a lower temperature growth mechanism becomes important at the longer residence time of the larger fires. Although not tested for as yet, there is a possibility that the larger fires produce a less graphitic smoke with a smaller carbon/hydrogen ratio compared to the smoke from smaller fires. These measurements will be made as part of future meso-scale experiments.

SMOKE PLUME TRAJECTORY

In recent years, advances in computational methods and hardware have made practical the use of techniques to simulate numerically the turbulent mixing of smoke in the atmosphere. In cooperative research between NIST and the Massachusetts Institute of Technology (MIT), a method has been developed to simulate smoke dispersion and settling from crude oil pool fires. Present capabilities are limited to analysis of smoke flow in a uniform wind. This simplifies the analysis to one of dispersion and settling of a negatively buoyant particulate laden flow. Smoke particulate position downwind of the burn is related directly to time, given the uniform wind field.

The model is started by initializing a plume shape as represented at its maximum stabilized altitude by an ellipse whose aspect ratio can be chosen to match an observed vertical and lateral extent of the smoke. The subsequent motion of the plume is calculated by applying the transport element method developed by

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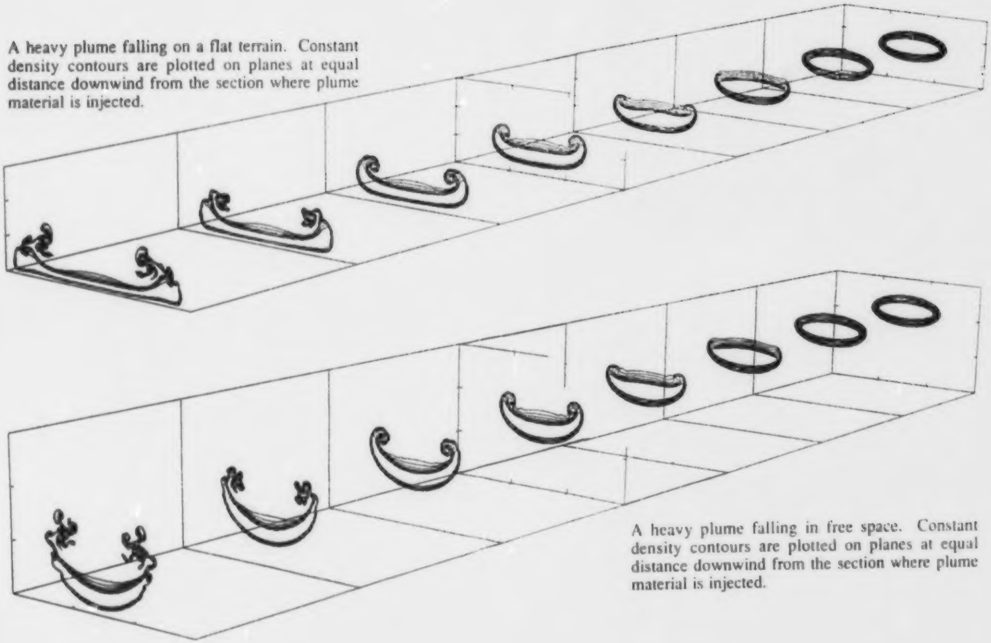
[1] Certain commercial equipment, instruments, and materials are identified in this paper to specify adequately the experimental procedure. In no case does such identification imply recommendation or endorsement by the National Institute of Standards and Technology, nor does it imply that the material or equipment identified is necessarily the best available for the purpose.



A heavy plume falling on a flat terrain. Constant density contours are plotted on planes at equal distance downwind from the section where plume material is injected.

A heavy plume falling in free space. Constant density contours are plotted on planes at equal distance downwind from the section where plume material is injected.

Figure 14 Calculated constant density smoke plume contours at eight locations separated by equal distances downwind from the initial station.

Ghoniem [14] to the mathematical model presented in earlier AMOP proceedings [4]. This calculation differs from many of the commonly used models of particulate or pollution transport in that no assumptions are made regarding the shape of the smoke density profiles in the plume as it proceeds downwind, nor is any empirical turbulent mixing rule applied. All calculations are based directly on the solutions to the equations of fluid mechanics.

To demonstrate the capabilities of the calculation method, two sample calculations are illustrated in figure 14. They show a set of constant density contours at eight locations separated by equal distances downwind from the initial station. The initial plume cross-section in each case is a 3:1 aspect ratio ellipse. The calculations differ only in that the center of the initial plume is 1/2 the plume width above the ground in the upper sequence, and there is no ground in the lower sequence. Comparison of the two simulations shows that for approximately the first half of the downwind trajectory, there is almost no ground effect on the plume development. Thus, as the initial plume altitude is raised further above the ground, more and more of the lower sequence will appear to characterize the plume mixing with the atmosphere. In particular, the development of the characteristic horseshoe shaped cross-section is quite evident. The shape is generated by the increasing concentration of buoyancy induced vorticity at the outer edges of the plume. This produces the intense mixing made visible by the secondary eddies which entrain large amounts of clear air into the plume at the end of the sequence. The modification of this picture due to the ground effect can be observed in the latter portions of the upper sequence. The flattening of the cross-sectional profile is followed by a rapid lateral spreading as the vortices concentrated at the edge of the plume generate their mirror images due to the presence of the ground. The induced image vortices generate the lateral ground level velocities which spread the smoke out.

The results allow some useful estimates to be made of particle deposition distances for oil spill scenarios, even in the absence of a complete plume model (one that accounts for plume rise and stabilization as well as settling). As an example, consider a crude oil pool of about 2.5×10^3 m^2 area burning in a fire resistant containment boom. Assuming a regression rate of 5.8×10^{-2} mm/s and a fifteen percent fuel/smoke conversion efficiency, a 18 kg/s mass flux of particulate matter is generated. Figure 15 shows the vertical and lateral extent of the plume as a function of distance downwind. The distance downwind is measured in units of

$$(LU)^{3/2}/(g\dot{m}/\rho_o)^{1/2}$$

Here L is the half depth (semi-minor axis) of the initial plume, U the wind speed, g the gravitational acceleration, $\dot{m}$ the particulate mass flux through the plume, and ρ_o the ambient air density. The vertical and lateral distances are measured in units of 10L. If the length L is taken as 300 m, and a 5 m/sec. wind is assumed, then the downwind deposition distance corresponding to seven distance

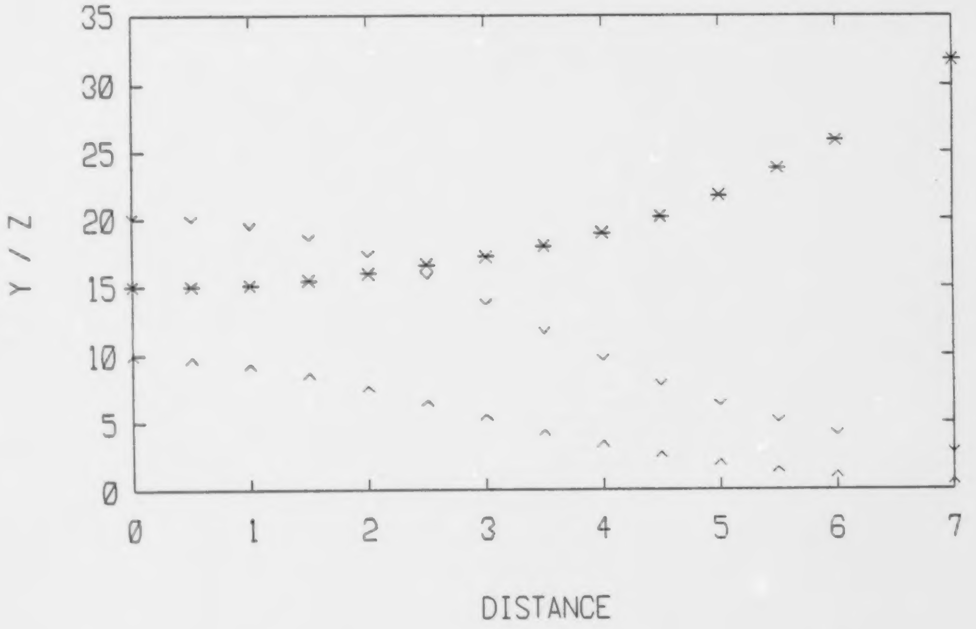


Figure 15 Calculated vertical and lateral extent of a smoke plume as a function of distance downwind. Shown are the variation of the elevation of the highest (V) and lowest (^) point on the plume center line, and the half width of the plume (*) with distance downwind.

units in figure 15 is about 28 km. Doubling the wind speed to 10 m/sec. would bring this distance to 80 km. The width would be approximately 2 km in either case.

The next stage of this work involves extending the model to study the positively buoyant thermal plume, including the effects of vertical wind shear and density stratification of the atmosphere. When that work is completed, the entire trajectory for the smoke particulate from generation at the fire to deposition downwind will be predicted. Data from meso-scale experiments will be used to evaluate the method. This methodology offers the promise of major improvements in predictive capability.

FUTURE PLANS

A series of meso-scale crude oil pool fires are planned. These pool fires up to 15 m x 15 m will provide an opportunity for measurements of crude oil burning characteristics, combustion products, and plume trajectory in a carefully planned and controlled field experiment. In addition to the data obtained from these fires, the experiments also serve as partial preparation for measurement in future offshore demonstrations of in-situ burn technology for oil spill response.

ACKNOWLEDGEMENTS

This work was a continuation of studies begun in 1985 as part of the Technology Assessment and Research Program for Offshore Minerals Operations managed by John Gregory and Ed Tennyson of Minerals Management Service. The research was funded jointly by the Minerals Management Service, U.S. Department of the Interior, the American Petroleum Institute, and the U.S. Coast Guard, Department of Transportation. Special technical assistance and cooperation was provided by Merv Fingas of the Technology Development and Technical Services Branch, Environment Canada and the Rod Terpin of the Environmental Protection Agency, Emergency Response Team in Edison, NJ.

In connection with the experiments at FRI in Japan, we would like to acknowledge Dr. Morikawa for his analysis of CO_2 and CO content in the bag samples collected by the portable smoke sampler and Dr. Hashimoto from Tokyo Science University for analysis of smoke samples which yielded the electron microscope pictures of smoke particulate used in this paper.

We are grateful for the opportunity provided by the fire fighters and instructors at the Navy's Farrier Firefighting Facility in Norfolk VA to observe and make measurements on large fuel oil fires as preparation for the meso-scale crude oil fire experiments.

The cooperation and hospitality of the U.S. Coast Guard Research and Development Center and the Fire and Safety Test Detachment in preparing a test facility for the meso-scale burning experiments has been outstanding in every respect.

The program of meso-scale burn experiments is coordinated through the Burn Evaluation Steering Team (BEST).

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MODIFICATION, SCALE-UP AND TESTING OF A 100 BBL/DAY SWIRLFIRE BURNER

by

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BACKGROUND

In 1987/88 a study of spill-generated oily material disposal requirements was conducted for the Coast Guard (S.L. Ross 1988); in it a recommendation was made to test the SWIRLFIRE rotary cup burner concept and ultimately produce a version capable of flaring 7 L/min (10 m^3/day = 63 bbl/day) of a wide variety of recovered oils, including emulsions.

In 1988/89, a prototype SWIRLFIRE (denoted here as Mark I) was built by Energetex Engineering and tested with a variety of oils and emulsions (S.L. Ross 1989). The burner proved capable of cleanly burning: water-free weathered crude oil at rates of 1.3 to 1.4 L/min (12 to 13 bbl/day); water-in-crude oil emulsions at rates, depending on the water content, up to 4.2 L/min (40 bbl/day); diesel fuel at a rate of 1.9 L/min (17 bbl/day) and waste engine oil at 1.24 L/min (11 bbl/day). A number of minor modifications to the burner design were suggested as were additional, maximum-capacity tests (i.e., disregarding smoke generation). The development and testing of a larger version was also suggested.

OBJECTIVE OF THE PRESENT STUDY

The objective of the present study was to develop a heli-transportable SWIRLFIRE rotary cup burner capable of disposing of 11 L/min (100 bbl/day) of crude oil, emulsion or petroleum product recovered from an oil spill.

GOALS

More specifically, the goals of the study were to:

- determine the maximum burn rate (i.e., disregarding smoke generation) of the Mark I SWIRLFIRE burner with low, medium and high viscosity oils and conduct long (about 1 hr) burns to test the mechanical reliability of the device.

- design and build an 11 L/min (100 bbl/day) version (denoted as Mark II) capable of being transported by a Bell-206 helicopter (ca 400 kg).

- test the Mark II SWIRLFIRE burner using a variety of fresh and weathered crudes, water-in-oil emulsions and oil products.

MAXIMUM BURN RATE TESTS WITH MARK I PROTOTYPE

Methods

The tests were conducted at a private residence near Woodlawn, Ontario on September 24, 1990. Diesel fuel and an Ontario crude oil, from which 10% of its volume had been artificially evaporated, were used to test the burner. Bunker "A" fuel oil was also tried but could not be drawn up the suction hose by the Mark I's gear pump at the prevailing temperatures (between 0 and 10°C). The properties of the two oils successfully burned were:

Test Oil	**Viscosity (mPas = cP)**	**Density (kg/m^3)**
10% evaporated crude[1]	10 @ 23.4°C	834 @ 21.8°C
Diesel[2]	3.9 @ 0°C	838 @ 0°C

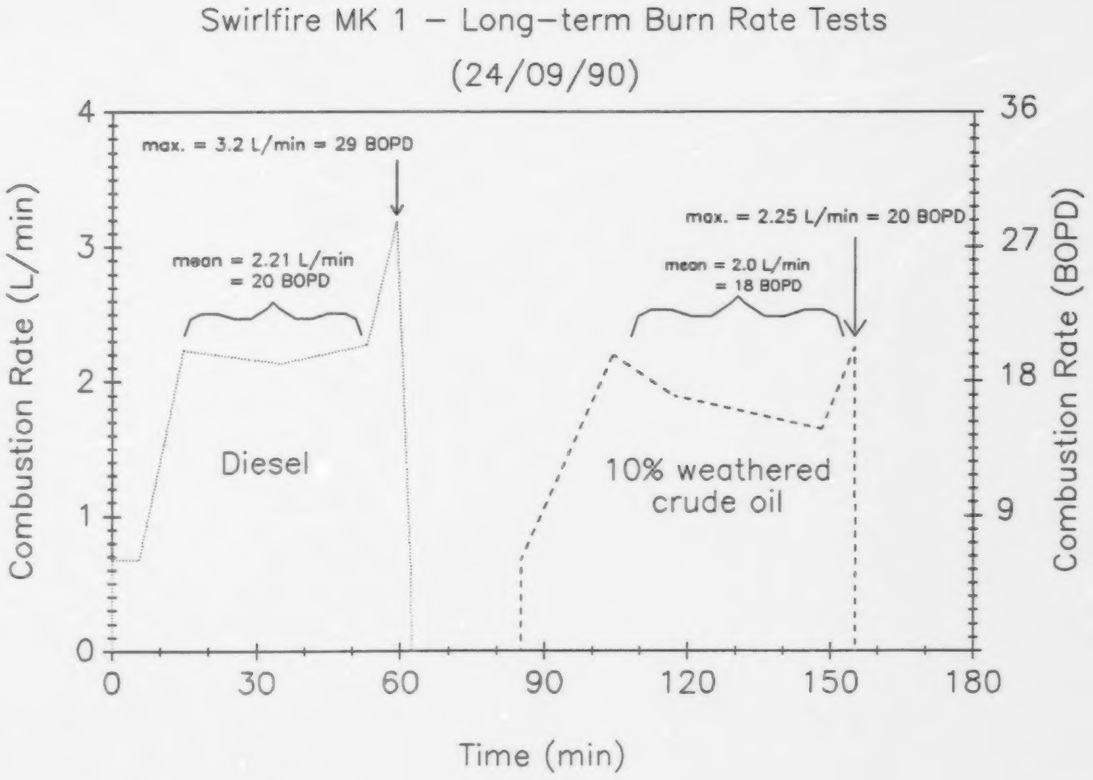
1 from S.L. Ross 1991
2 from Bobra 1990

Results

Figure 1 shows the results of the tests. Diesel fuel was burned at a mean rate of 2.2 L/min (20 bbl/day or BOPD = Barrels of Oil Per Day) for a period of about 55 minutes followed by a 5 minute burn at 3.2 L/min (29 bbl/day). Figure 2 shows the Mark I SWIRLFIRE burning diesel oil at a rate of 2.2 L/min (20 bbl/day); note that very little smoke is being emitted, the steam rising from the ground is from rainwater on the sand pad in front of the burner. Some smoke was being emitted from the end of the flame at a burn rate of 3.2 L/min (29 bbl/day). The opacity of this smoke was Ringelmann No. 1 or less. All the oil was burning in the flame even at this flowrate; no fallout was visible. At a flowrate of 3.2 L/min the radiant heat from the flame caused the rubber wheels at the front of the burner to smoke. A sheet of corrugated steel was placed in front of the burner wheels to prevent this.

During the second half of the tests the Mark I SWIRLFIRE burned 10% evaporated Ontario crude oil at a mean rate of 2.0 L/min (18 bbl/day) with a peak rate of 2.25 L/min (20 bbl/day) at the end of the tests. At a burn rate of 2.0 L/min no smoke or fallout was noted; at 2.25 L/min some smoke (Ringelmann 1 to 2) was observed coming from the end of the flame, although no fallout was noted.

Figure 1


Swirlfire MK 1 – Long-term Burn Rate Tests
(24/09/90)
Combustion Rate (L/min)
0
1
2
3
4
Combustion Rate (BOPD)
9
18
27
36
Time (min)
0
30
60
90
120
150
180
max. = 3.2 L/min = 29 BOPD
mean = 2.21 L/min = 20 BOPD
Diesel
max. = 2.25 L/min = 20 BOPD
mean = 2.0 L/min = 18 BOPD
10% weathered crude oil

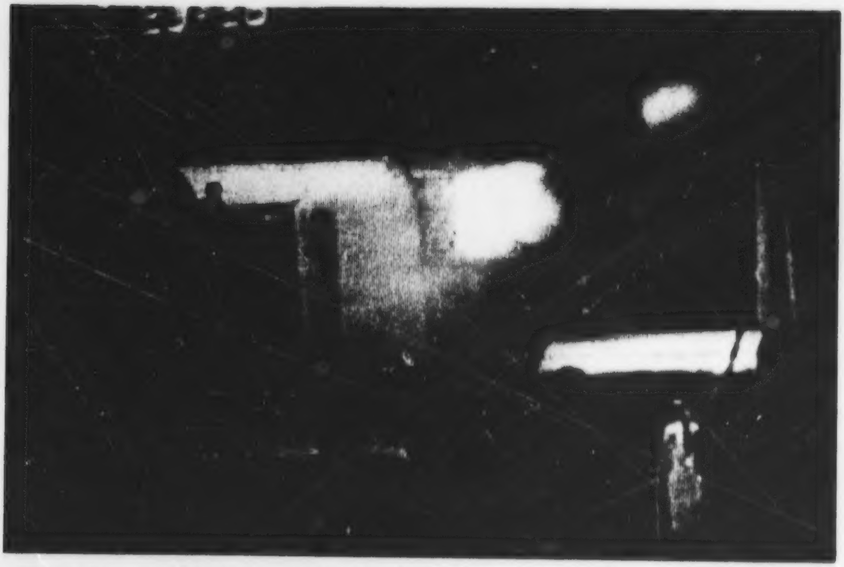


Figure 2 - Mark I prototype burning 2.2 L/min of diesel

Figure 3 - The Mark II prototype SWIRLFIRE burner

In general, with the exception of a small leakage from the bolt holes in the collar on the rotating seal (noted previously in S.L. Ross 1989) and the need to provide a radiation seal for the front wheels, the Mark I SWIRLFIRE proved to be durable.

Based on these test results the nominal capacity of this burner would be 2.2 L/min (20 bbl/day) of water-free oil.

GENERAL LAYOUT OF MARK II PROTOTYPE

As a result of the Mark I tests, a prototype 100 bbl/day SWIRLFIRE (denoted here as Mark II) was designed and constructed by Energetex Engineering. This version incorporated many of the previous recommendations (Buist 1989).

Figure 3 shows the Mark II SWIRLFIRE prototype being lifted off a truck. The Mark II prototype weighs 1590 kg, including fuel, and is a fully self-contained unit. The 1.5 m high x 1.6 m x 2.6 m mechanical compartment, mounted on steel wheels, supports the 1.1 m long x 0.6 m diameter plenum which in turn supports the 0.8 m diameter stainless steel combustion head. The burner was also supplied with an external diesel tank which was not used during the tests.

Figure 4 shows the inside of the mechanical compartment looking into the rear through the opened wire-mesh doors. On the left is the radiator for the water-cooled diesel (Lister-Petter Model LPWS4), a 4-cylinder model producing 23 kW (31 HP) @ 2500 rpm and 28 kW (37.5 HP) @ 3600 rpm. Just to the right of the centre strut is the engine and flow control panel, consisting of a key, glow-plug activator switch, tachometer (0-3500 rpm) and throttle for the diesel and a needle-type flow control valve, a ball valve, a pressure meter (0-100 psi) and a pressure relief valve (for flow recycling back to the pump suction) for control of the fluid to the combustion head. The engine drives the feed pump, fan and rotary cup via "V" belts and sheaves at the following speed ratios:

Engine Speed	**Fan Speed**	**Pump Speed**	**Cup Speed**
min. 1000 rpm	600 rpm	480 rpm	1600 rpm
max. 2500 rpm	1500 rpm	1200 rpm	4000 rpm

On the right-hand wall of the mechanical compartment is the internal diesel fuel tank for the engine; below the fuel tank is the suction hose for the oil feed pump to the burner head.

Just visible in Figure 4 at the far end of the mechanical compartment is the Buffalo Forge Model MW45 centrifugal fan capable of moving 243 m^3/min (8600 cfm) of air against a pressure of 3 kPa (12 inches of water) at a speed of 1600 rpm while drawing 19.4 kW (26 hp). Between the fan and the engine/flow control panel is a priming funnel/valve for the feed pump.

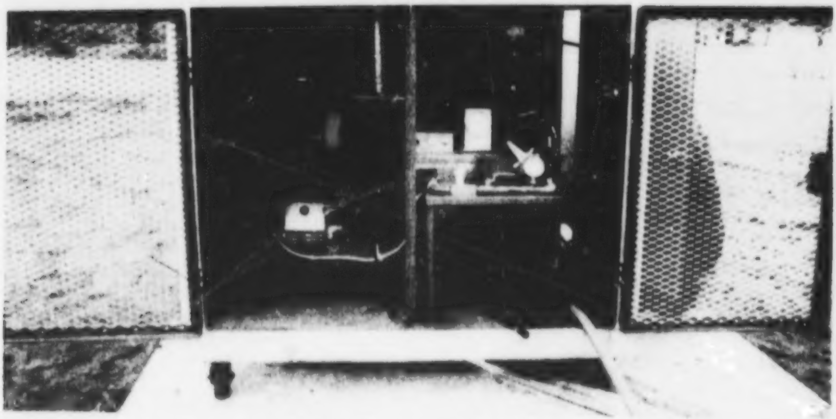


Figure 4 - Rear-view of Mark II prototype looking into mechanical compartment

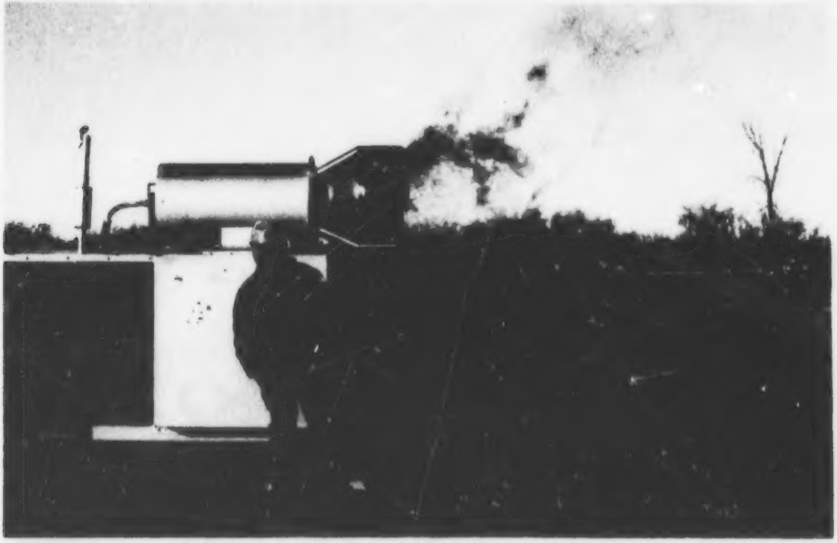


Figure 5 - Right-hand side view of Mark II prototype

Figure 5 shows the burner with the right-hand (with reference to Figure 4) compartment door open. Just visible is the Albany Pump size 10 gear pump used to feed oil to the burner head. With the engine at 1400 rpm the pump discharges 18.9 L/min of 1000 mPas (cP) fluid against a head of 350 kPa (50 psi); under the same conditions the pump discharges 17.0 L/min of 10,000 mPas fluid. At the maximum engine speed of 2500 rpm the pump discharges 31 L/min of 1000 mPas (cp) fluid against a head of 350 kPa (50 psi); under these conditions the pump draws 0.75 kW (1 hp).

The stainless steel combustion head (Figure 6) includes an ignition port, through which a burning torch is inserted, the cylindrical combustion chamber and air recirculation tubes. Beneath the combustion head is the wheel that operates a damper on the blower to regulate air flow to the combustion head. Air is blown up into the bottom of the plenum through a square transition piece; from there the air enters the combustion head through an annulus past the rotating cup. Droplets of fuel are atomized off the edge of the cup by this air and ignite in the combustion chamber. There is a short steel cylinder mounted inside the combustion head that acts as a secondary atomization area (using the principle of "hot plate" atomization) for viscous fuels. Four recirculation tubes direct air from the plenum backwards from the front of the combustion head towards the rotating cup to provide enhanced fuel/air mixing.

TESTING OF THE MARK II PROTOTYPE

Methods

These tests were conducted at the site of the Coast Guard Marine Radio Station in Cardinal, Ontario on March 19 and 20, 1991. The site was prepared by the placement of a 10 m x 10 m x 15 cm sand pad. The Mark II prototype was placed on 2 sheets of plywood (to allow its rotation in response to changes in wind direction) at the upwind corner of the sand pad.

The test oils used included diesel, Hibernia crude oil and Alberta Sweet Mixed Blend (ASMB) crude oil; it had been intended to test a Bunker "C" oil but, at the ambient temperatures of about 0°C, the Bunker "C" had gelled and was not tested. The properties of the fresh oils were (Bobra 1990):

Test Oil	**Viscosity** (mPas = cP @ 0°C)	**Density** (kg/m^3 @ 0°C)
Diesel	3.9	838
ASMB	47	847
Hibernia	10,000	877

A sample of the ASMB crude was artificially weathered by sparging air through it until it had lost 13% of its volume to evaporation. This would increase its viscosity to about 5000 cp at 0°C (Bobra 1990). Samples of the Hibernia oil were artificially weathered to

Figure 6 -Front-end view of Mark II prototype

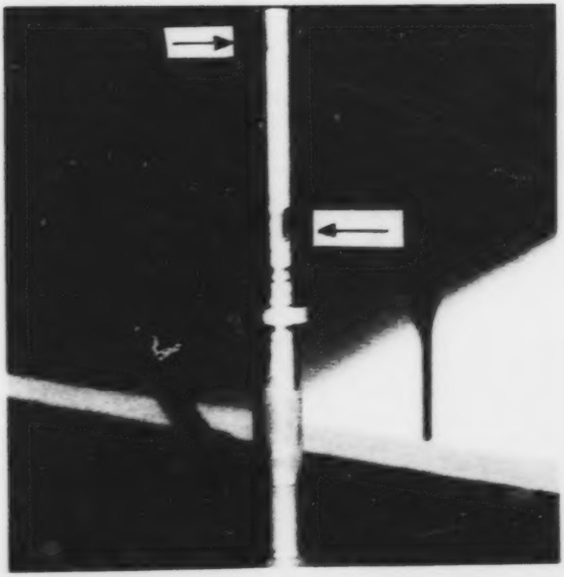


Figure 7-Worn shaft of hose connector

13% and 20% evaporated; the viscosity of these samples would be in the 100,000 to 300,000 cP range (Bobra 1990). These high viscosities are a direct result of the pour points of these weathered oils greatly exceeding ambient (0°C) temperatures.

Water-in-oil emulsions, created in a 50 L plastic garbage can using a paint mixing attachment on a ½" electric drill, were also tested. Emulsions of 33% and 50% by volume water were used.

Results

Pre-Test Adjustments. Prior to commencing the tests three relatively minor problems with the Mark II prototype had to be corrected. The first involved a slow, but steady leakage of oil from the rotating seal located in the shaft at the back of the plenum. The assembly was taken apart and the cause of the leakage determined to be wear on the shaft of the hose connector (Figure 7). The wear was concluded to have been caused by overtightening of the U-bolt holding the connector.

The second problem was an air bubble in the pump recirculation line that could not be purged. This resulted in sporadic failure of the pump to deliver fuel to the burner and flame extinction.

The third problem related to achieving the proper air flowrate and distribution for burning. A damper had been retrofitted to the Mark II prototype because, even with the engine idling, the air velocity in the combustion head was too high for a rag torch or oxy-acetylene torch to remain lit. It took several attempts to determine the proper balance of air flow and fuel flow to provide a stable flame.

Oil Burning Tests. Figure 8 and Table 1 show a summary of the test burn results. The first oil tested was diesel fuel; a maximum burn rate (with the flow control valve fully open) of 11.9 L/min (108 bbl/day) was achieved. This test was interrupted by a small grass fire ignited by diesel fuel sprayed onto the sand pad and grass in front of the burner during previous trial runs. The burn itself was very clean with no smoke (Figure 9); however it was clear that the fuel atomization for the Mark II prototype was not as good as in the Mark I prototype (note the burning fuel droplets at the bottom end of the flame in Figure 9) and that the swirling action of the flame noted during the Mark I prototype trials was not evident during these tests. These shortcomings should be easily overcome by simple changes in the combustion head and plenum; these possible changes are listed in the next section.

Figure 10 shows the Mark II prototype consuming 9.3 L/min (84 bbl/day) of fresh Hibernia crude oil. The less than perfect atomization is evident as is some smoke; some droplet fallout was also observed. Figure 11 shows the prototype burning 12.1 L/min (110 bbl/day) of 13% evaporated ASMB crude. With this less viscous oil better atomization was achieved allowing a higher burn rate (the flow control valve was fully open). The highest burn rate (13.9 L/min = 126 bbl/day) was achieved with fresh ASMB, the least viscous of the crudes tested. With this oil a clean burn was produced but oil droplets were still ejected from the flame (Figure 12).

Figure 8

Swirlfire MK 2 – Burn Tests Results

(19/03/91)

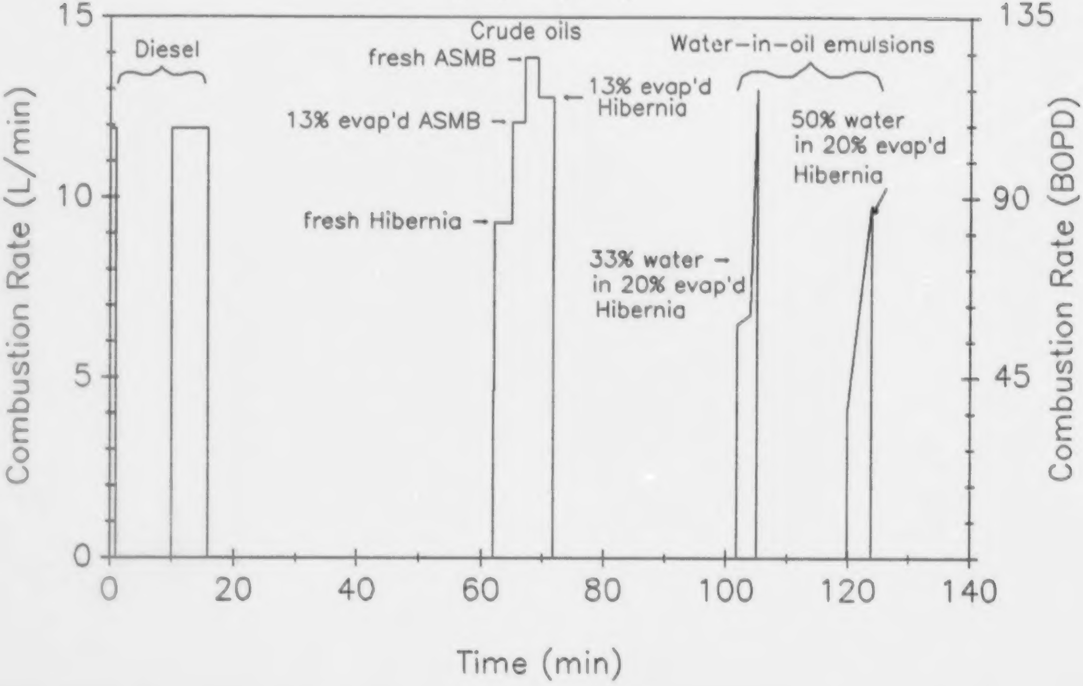


TABLE 1

Preliminary Test Results
Swirlfire MK II
Cardinal, Ontario - March 19,1991

Oil Type	Time (min:sec)	Oil Level (cm)	Volumetric Flowrate (L/min)	(BOPD)
Diesel	0:00	76*		
			11.9	108
	5:46	48		
Fresh Hibernia	0:00	30		
			9.3	84
	2:52	11		
13 % Evap'd Hibernia	0:00	33		
			12.8	116
	2:39	9		
20 % Evap'd Hibernia with 33 % emulsified water	0:00	25		
			6.46	59
	1:05	18		
			6.74	61
	2:05	13		
			13.0	118
	3:10	2		
20 % Evap'd Hibernia with 50 % emulsified water	0:00	30		
			4.1	37
	3:20	22		
			9.8	89
	3:55	18		
Fresh ASMB	0:00	32		
			13.9	126
	2:07	11		
13 % Evap'd ASMB	0:00	30		
			12.1	110
	2:05	12		

* diesel drawn from a 220 L drum; all crudes drawn from a 50 L garbage can

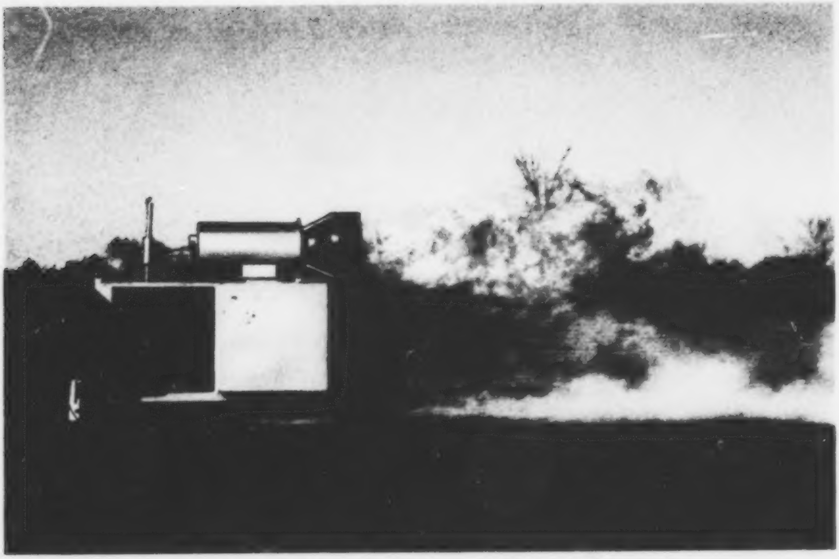


Figure 9 - Mark II prototype burning diesel fuel at 11.9 L/min

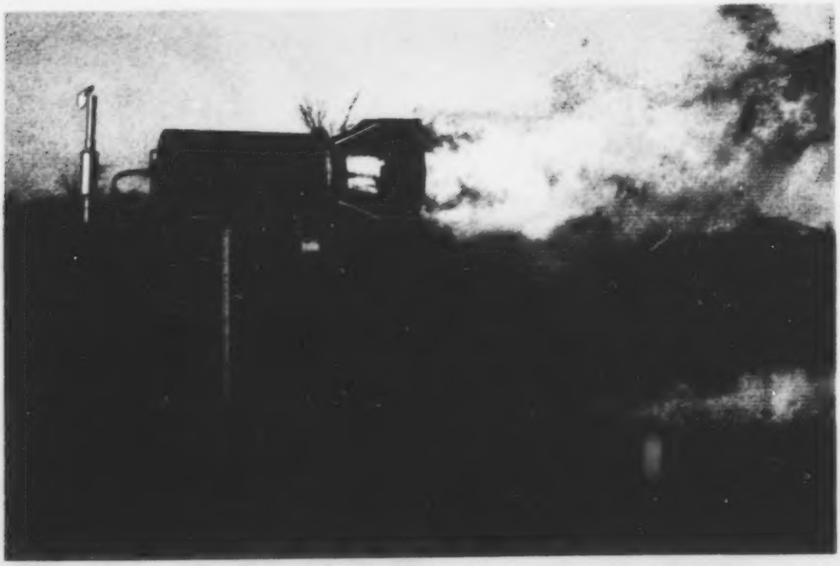


Figure 10 - Mark II prototype burning fresh Hibernia crude at 9.3 L/min

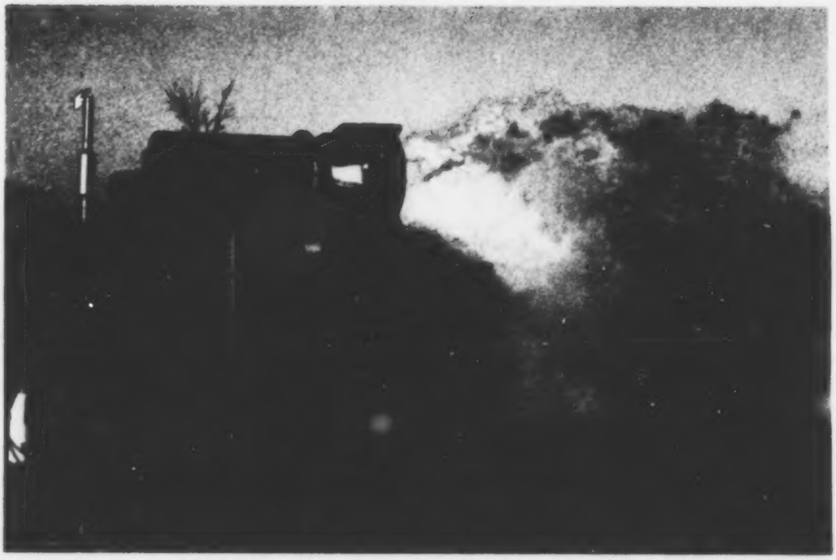


Figure 11 - Mark II prototype burning 12.1 L/min of 13% evaporated ASMB crude

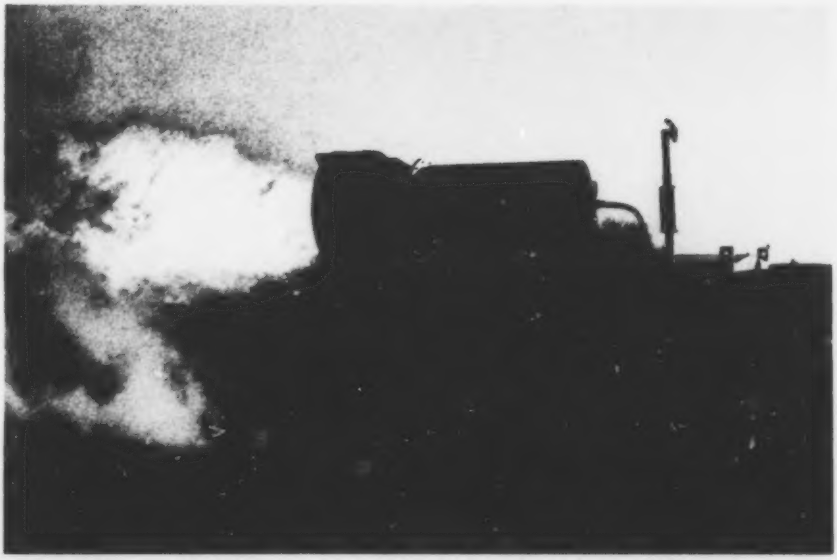


Figure 12 - Mark II prototype burning 13.9 L/min of fresh ASMB crude

Figure 13 shows the burn of 13% evaporated Hibernia oil at the same air and fuel settings as for the previous test; a clean burn was achieved but the fuel flow seemed to be restricted by the needle valve. A burn rate of 12.8 L/min (116 bbl/day) was measured.

The last two tests involved burning water-in-oil emulsions. The first of these resulted in the successful, clean burn of up to 13 L/min (118 bbl/day) of 33% water in 20% evaporated Hibernia crude. Significant numbers of droplets were ejected from the flame (Figure 14).

The final test involved burning a 50% water-in-20% evaporated Hibernia crude oil emulsion (Figure 15). This mixture did burn with a stable flame; however large droplets and foam were ejected from the flame (sufficient to pool and ignite on the sand pad) and the flame was somewhat smokey at a consumption rate of 9.8 L/min (89 bbl/day). Again, the maximum burn rate seemed to be fuel flowrate limited (probably due to restricted flow of this very viscous fuel through the needle valve). A slug of water drawn from the bottom of the pail in which the emulsion was mixed terminated this test by extinguishing the flame.

In general the prototype worked best at a reduced air flow (i.e., with the damper partially closed) and with the fuel flow control needle valve fully open. The needle valve seems to restrict the maximum possible flowrate to the combustion head to about 40 to 70% of the pump's rated capacity. It also seems that, as presently configured, more air enters the top of the combustion head than the bottom. Performance seemed to improve at higher engine speeds (2000 rpm vs. 1400 rpm). It was noted that a resonant vibration was set up at an engine speed of 1500 rpm.

Recommendations Arising from the Mark II Prototype Tests

As a result of the tests 14 recommendations for improvements to the prototype have been made. These are:

1. The existing model should be retrofitted with a larger diameter rotary cup in order to increase atomizing air velocity, reduce overall air flowrate and improve air/fuel droplet mixing.
2. Vanes should be retrofitted to the existing prototype in the plenum itself or on the rotating shaft behind the combustion head to impart a swirling action to the forced air as it enters the combustion head.
3. The needle valve regulating fuel flow to the combustion head should be replaced on the existing version with a valve that offers less resistance to flow (such as a ball or gate valve).
4. The fan on the existing model should be slowed down by replacement of its sheaves with larger ones.
5. The existing prototype should be retested with diesel fuel; during these tests each of the modifications in recommendations 1-4 should be made one at a time to determine their individual effect on the combustion process.
6. The existing U-bolt holding the hose connector in the rotating shaft should be modified to incorporate a sponge or soft rubber lining to allow a friction grip on the connector without imposing a vertical or lateral load on the internal needle bearings.

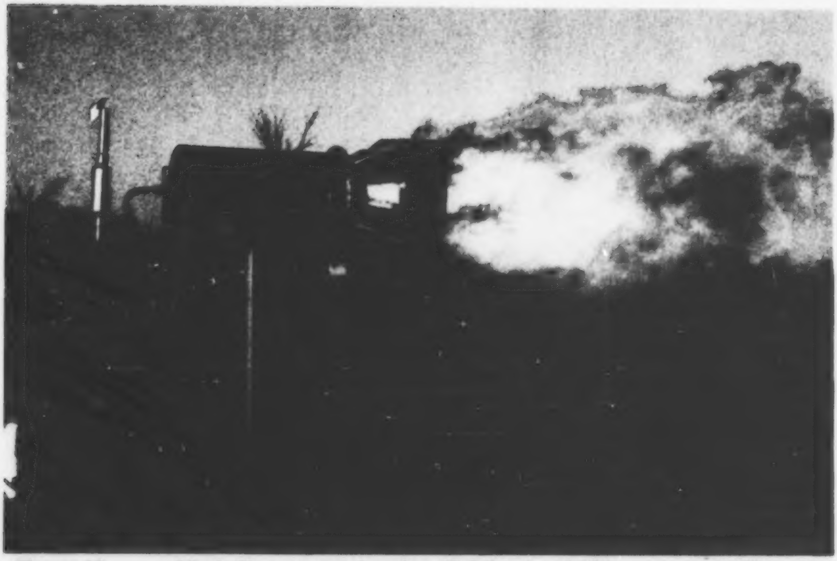


Figure 13 - Mark II prototype burning 12.8 L/min of 13% evaporated Hibernia crude

Figure 14 - Mark II prototype burning 13 L/min of 33% water-in-20% evaporated Hibernia crude emulsion

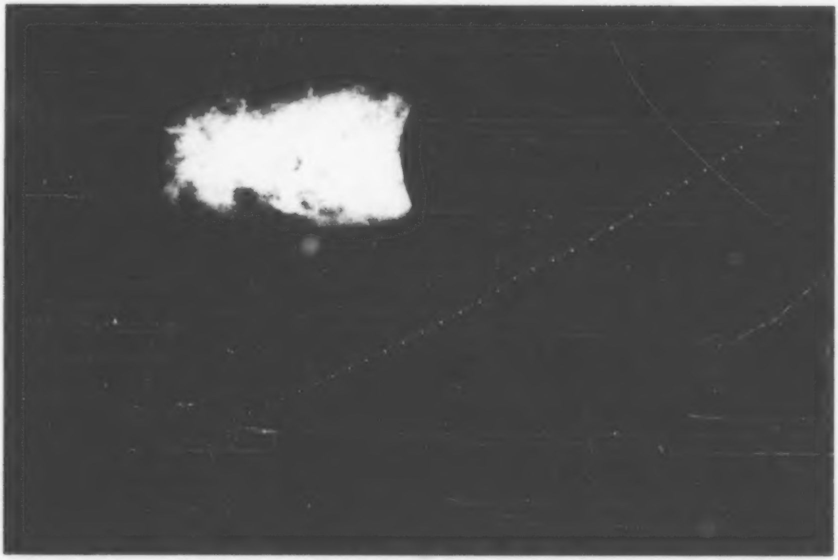


Figure 15 - Mark II prototype burning 50% water-in-20% evaporated Hibernia crude emulsion at 9.8 L/min.

7. An air distribution system may be required in the plenum to more evenly distribute air between the top and bottom halves of the combustion head.
8. Consideration should be given to increasing the number, size and/or location of the combustion air recycling tubes in the combustion head.
9. The feed pump recirculation system needs redesign, including moving the priming system for better access, allowing recycle back to the oil source (i.e., drum, portatank, etc.) and provision of an air bleed in the recycle system.
10. A slot is required to allow passage of the suction hose out of the burner housing when the access doors are closed.
11. The suction line from the oil source to the pump inlet should be of all 1" hose or pipe not a mix of 1" and ½" sizes.
12. The damper control wheel for the fan (if it is still required in future models) needs to be relocated to the side or back of the burner.
13. The geometry of the combustion head could be altered for better fuel/air mixing (i.e., a longer cylindrical section and/or a smaller, venturi-shaped outlet).
14. Consideration should be given to developing an optional preheater element to be placed on the ground under the flame for preheating.

It is noted that the weight goal (400 kg) for the 100 bbl/day prototype was not achieved; it was decided during the design stage for the Mark II prototype that the simplicity of design and operation offered by a single, self-contained unit was worth the weight penalty. The existing prototype is still portable by medium-lift helicopters such as the Bell 212 or 205A-1 (Huey), Aerospatiale AS 332L (Super Puma) and the Sikorski S-61 and Sea King.

If required, the 100 bbl/day SWIRLFIRE could be redesigned into two packages, each weighing less than 900 kg; however it is unlikely that it could be redesigned to meet the goal of heliportability by a Bell 206.

SUMMARY

The original Mark I prototype SWIRLFIRE burner was tested for its maximum capacity for long-term operations. The device successfully burned up to 2.25 L/min (20 bbl/day) of a weathered crude oil and up to 3.2 L/min (29 bbl/day) of diesel fuel.

With this data and recommendations from previous trials a 100 bbl/day prototype was designed and constructed by Energetex Engineering. This Mark II prototype was tested with a variety of oils and proved successful in burning diesel fuel at 11.9 L/min (109 bbl/day); crude oils at up to 13.9 L/min (126 bbl/day); and, emulsions with water contents up to 50% at rates up to 13 L/min (118 bbl/day).

Recommendations were made to improve fuel atomization and air/fuel mixing in the Mark II prototype and thus eliminate droplet fallout and flame blowout. Suggestions to further enhance the prototypes capabilities were also made.

ACKNOWLEDGEMENTS

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SOLVENT EXTRACTION AND RECOVERY OF PETROLEUM-DERIVED HYDROCARBONS FROM SOIL

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Environment Canada
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INTRODUCTION

The Emergencies Engineering Division (EED) of Environment Canada, is currently investigating methods of removing petroleum hydrocarbons from soil and shoreline material. As part of this investigation, EED is currently examining the use of solvent extraction for this application, as a project jointly funded by EED and the National Groundwater and Soil Remediation Program (GASReP)

Solvent extraction is a technology which has been used effectively in industry for several decades, but it has only been recently that the technology has been used in the soil remediation field. Many of the existing soil remediation units use proprietary solvents which, in many cases, results in higher operating costs. For this reason, EED decided to evaluate solvents which are readily available and relatively inexpensive. As part of this project, two solvents, hexane and natural gas condenste, are being studied in terms of their ability to remove petroleum hydrocarbons from soil. It is hoped that these solvents can be incorporated into existing solvent extraction/soil remediation systems and beach cleaning processes.

EED's mandate to research, develop and demonstrate technologies for the remediation of chemical and oil spills led the division to investigate technologies for the remediation of contaminated soil and beach material. The technologies looked at had to be easy to transport, setup and operate so that they could be used in emergency situation. It was felt that solvent extraction could meet these requirements.

The solvent extraction process would have to be simple so that it could be a mobile unit which could be brought directly to the contaminated area, set up quickly and not require specialized labour. In order to meet these requirements, the system should incorporate inexpensive and easily obtainable solvents and run at atmospheric pressure.

In 1989 EED became involved in the GASReP program and put forth a proposal to investigate the use of solvent extraction as a method of removing petroleum hydrocarbons from soil. The original intent was to begin by studying hexane as a solvent, but it was suggested that natural gas condensate (NGC) should also be investigated. NGC was recommended for this process because a significant number of the compounds found in the NGC are considered solvents for petroleum hydrocarbons. NGC is also considered a low-demand product of the petroleum refining process, making it inexpensive in comparison with pure solvents. In the case where NGC is used, the raw condensate mixture will have to be pre-distilled in order to produce a useable solvent.

To date EED has used a laboratory scale solvent extraction process to compare the two solvents, using three types of soil and a light crude oil (weathered and un-weathered) to create simulated contaminated soils. These soils and solvents have also been used to optimize the mixing portion of the extraction process.

The next stage of the evaluation is to set up a bench scale system which will use the simulated contaminated soils. The use of actual contaminated soil samples to evaluate the solvent extraction process is also planned during this stage.

MATERIALS FOR LABORATORY SCALE TESTING

Soils

For the laboratory scale portion of the tests three types of soils were used, a sandy soil, a peat soil and a silty/clay soil. For simplicity, these soils will be named sand, peat and clay respectively, throughout the paper. Table 1 shows the results of the mechanical analysis performed on the soils. The percent moisture and density analysis were performed in house by EED. The Wastes and Chemicals Division of Alberta Environment performed the remaining mechanical analysis for the sand and peat soils and the Geological Survey of Canada performed the particle size distribution for the clay soil.

TABLE 1: SOIL MECHANICAL ANALYSIS

SAMPLE	SAND	PEAT	CLAY
$CaCl_2$ pH	5.07	4.88	NA
% TOTAL CARBON[1] $\%CaCO_3$	0.84 <0.7	11.6 <0.7	NA NA
LOSS ON IGNITION AT 420°C	2.08	26.85	NA
% SAND (WT)[2]	86.4	85.6	0.5
% SILT (WT)	6.4	11.2	14.9
% CLAY (WT)	7.2	3.2	84.5
TEXTURE	LOAMY SAND	LOAMY SAND	CLAY
AVERAGE % MOISTURE (WT)	9.0	54.3	35.2
SPECIFIC SURFACE (m^2/g)	50.3	NA	NA

1. %organic carbon = %total carbon - $\%CaCO_3$
2. The values for percent sand, peat and clay are based on the size distribution of the inorganic particles present in the soil samples.

Solvents

Solvent grade hexane (98%) and hexane recycled from the lab-scale process, were used for the lab-scale solvent comparison.

One barrel of natural gas condensate was donated to EED by Parklands Refinery Limited of Alberta. Table 2 shows the approximate weight percentages of the various components contained in a condensate similar to the condensate received. The mass fractions and boiling ranges shown are for a Mobile Harmattan area gas plant condensate based on analysis performed by Core Laboratories of Alberta on May 9, 1990. Figure 1 shows the percent of light ends recovered at specific distillation temperature cutoffs, according to EED's distillation results.

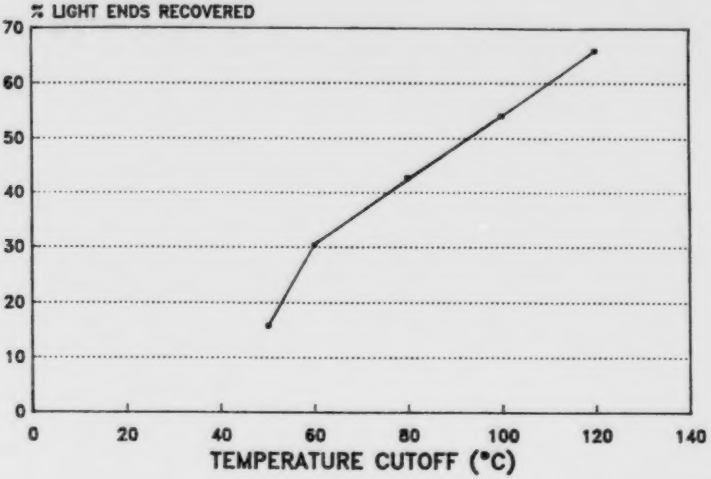
The NGC was pre-distilled during these tests so that the fraction used as the solvent was the boiling range between 50°C and 80°C. It was found that this distillation fraction made up approximately 26% of the NGC sample. In the remainder of this paper when NGC is mentioned it is this 26% fraction which is being referred to.

TABLE 2: COMPOSITION OF PARKLAND'S NATURAL GAS CONDENSATE

COMPOUND	MASS FRACTION	BOILING POINT RANGE (°C)
HEXANES	0.138	36.1 - 68.9
HEPTANES	0.089	68.9 - 98.3
OCTANES	0.070	98.3 - 125.6
NONANES	0.040	125.6 - 150.6
DECANES	0.046	150.6 - 173.9
>DECANES	0.139	173.9 plus
CYCLOPENTANE	0.001	48.9
METHYLCYCLOPENTANE	0.021	72.2
BENZENE	0.016	80.0
CYCLOHEXANE	0.016	81.1
METHYLCYCLOHEXANE	0.027	101.1
TOLUENE	0.037	110.6
ETHYLBENZENE,p+m-XYLENE	0.036	136 - 138.9
o-XYLENE	0.008	144.4
1,2,4 TRIMETHYLBENZENE	0.009	168.9
TOTAL[1]	0.693	

[1] The remaining portion of the mass fraction is composed of unclassified compounds.

FIGURE 1: NATURAL GAS CONDENSATE DISTILLATION FRACTIONS



Petroleum Hydrocarbons

The oils to be used to contaminate the soil samples were a light crude oil, a diesel and a bunker C. The crude oil was obtained from an Esso Petroleum site near Sarnia, Ontario. The diesel and bunker C are being obtained locally.

Only the light crude oil has been used in the tests performed to date. This oil was used in both its weathered and un-weathered state. Once the pilot scale process has been assembled the bunker C and diesel oil, as well as the crude oil will be incorporated in the test protocol.

METHODS FOR LABORATORY SCALE TESTING

Solvent Extraction Comparison Method

In order to perform a rough comparison between hexane and NGC as solvents, a simple solvent extraction method was used, allowing several tests to be performed in a short period of time.

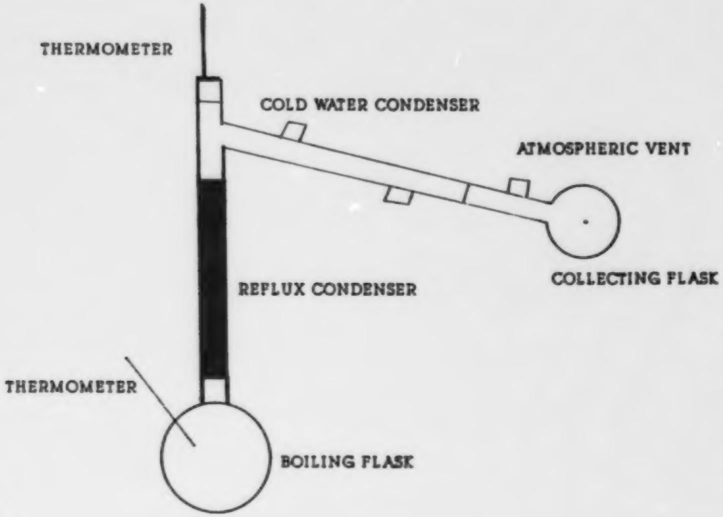
Because of initial difficulties in determining the transport of the water during the extraction process, all moisture was removed from the soil during this stage of the testing, by drying the soil in an oven. The soil then placed in a fleaker and was contaminated with the oil using a pipette. The fleaker was capped and let stand in a fumehood for 24 hours to allow the oil to absorb into the soil. The fleaker was re-weighed in order to account for any loss of volatile compounds.

The desired amount of solvent was added to the fleaker and the fleaker was shaken for one minute. The soil was then allowed to settle for 30 minutes or until there was no visible cloudiness in the solvent layer. The extracted liquid was decanted into a boiling flask and attached to the distillation apparatus shown in Figure 2. The extracted liquid was then distilled in order to collect the pure solvent in the top flask. The boiling cut-off (ie. the temperature at top of reflux condenser) for the hexane was 68°C and the cut-off for NGC was 86°C. The recovered soils were dried in an oven, at 90°C, in order to drive off any excess volatiles. The weight of the soil, before and after drying was recorded and incorporated into the system's mass balance.

The following variables were tested during this stage of the experimentation:
- Soil type: sand, peat, clay;
- Oil type: Ontario light crude;
- Solvent type: hexane, natural gas condensate;
- Percent oil contamination: 0%,1%,3%,5% and 10% (wt oil/wt soil);
- Number of extractions: one,
- Ratio of solvent to soil mixture: 1:1,2:1, and 3:1 (by weight).

During this stage of the testing most of the analytical work was gravimetric. In order to perform mass balance on the system, mass measurements were taken after each step in the extraction process. Using this method the percent oil recoveries were consistently over 100% mainly because it was difficult to trace the path of the water and the volatiles in the system. For this reason other analytical methods were investigated.

FIGURE 2: LAB-SCALE DISTILLATION APPARATUS


THERMOMETER
COLD WATER CONDENSER
ATMOSPHERIC VENT
COLLECTING FLASK
REFLUX CONDENSER
THERMOMETER
BOILING FLASK

Method With Ball Mill

The next stage of testing involved the optimization of the mixing stage of the process. In order to mix the solvent and contaminated soils thoroughly and consistently a ball mill was used. At this point the method for contaminating the soils was altered. The new method involved retaining the moisture in the soil. Approximately four centimeters of soil was placed in a 12cm by 12cm perforated tray. The weight of the soil in the tray was determined Oil was added to the soil until the oil seeped oit the perforations, resulting in a contaminated soil saturated with oil (usually 20 to 30% for the sand and 30 to 40% for peat). This allowed for the investigation of the solvents' effect at high oil contaminations. The tray was allowed to sit in the fume hood. After 16 hours the pan was re-weighed in order to determine the amount of oil in the soil.

Using the above method the effectiveness of hexane as a solvent was examined using weathered and un-weathered crude oil and varying solvent to soil ratios. Using the weathered oil removed the need to determine the quantity of volatile organics lost during the process. In order to create the weathered crude, the oil was stirred in an open container for 16 hours. It was determined that stirring this specific oil for greater than 16 hours resulted in no further volatile loss.

Approximately 200g of contaminated soil and the desired amount of solvent were added to the ball mill jar. The ball mill was run at the desired speed for the desired mixing time. The solvent layer was then decanted and distilled using the same procedure as in the solvent comparison method.

The following variables were tested during this stage of the experimentation:
- Soil types: sand;
- Oil type: Ontario light crude oil;
- Solvent type: hexane;
- Ball mill speed: 30%, 60%, 75% and 90%
  (31rpm, 49rpm, 58rpm and 67rpm);
- Ball mill mixing time: 30s, 60s, 180s
- Percent oil contamination: saturation (approx. 20wt%)
- Total solvent to soil ratio: 2:1
- Number of extraction: 2 (ie. 2 times 1:1 solvent/soil)
  3 (ie. 3 times 2:3 solvent/soil)
  4 (ie. 4 times 1:2 solvent/soil)

During this stage of the testing gravimetric analysis was used as in the previous method but the extracted liquids, before and after distillation were analyzed using gas chromatographic/flame ionization (GC/FID) methods and UV spectrophotometric methods.

The GC/FID methods gave some indication of the composition of the extracted liquids, in terms of light and heavy ends. As well GC/FID was used to determine the purity of the distilled solvent. The UV spectrophotometry method was used to determine the percent of oil in the extracted liquid. This was done by creating standard solutions of oil in solvent and producing calibration curves using various wavelengths.

As with the previous method the oil recovery percentage remained greater than 100% for almost all runs and it was felt that in order to correctly determine the oil recovery percentages, the recovered soils must be analyzed, for the percent of oil remaining, using a freon extraction method. This method determines the total oil and grease in the sample. The evaporation period required for this method renders it ineffective for determining the mass of volatile compounds, but because the soils are already dried in the fumehood after the hexane extraction process, it is assumed that there will be an undetectable amount of volatile compounds remaining in the soil, resulting from the solvent extraction process.

RESULTS

Figure 3 shows the oil recoveries obtained during the solvent comparison portion of the testing. These graphs show the variability of the oil recovery versus the solvent type, soil type, percent oil contamination and oil to solvent ratio. At this point in the testing the soils were dried prior to testing and were not analyzed using the freon extraction method. The oil recovery percents shown in these graphs were calculated by dividing the mass of the heavy distillation fraction by the mass of oil in the soil at the time the solvent was added. It should be assumed that in all cases these numbers are slightly high because the heavy distillation fraction contained some suspended solids and organics originating in the soil especially the peat. This explains why the oil recovery is greater than 100% during some runs. For this reason these numbers should only be used for comparison purposes and not actual removal quantities.

During the ball mill optimization tests, the soils to be contaminated were not dried and therefore the water originally found in the sample had to be incorporated in the mass balance on the system. During these tests it was observed that the decanted liquid was homogeneous. Since this liquid is hydrophobic it can then be assumed that the water originally in the soil samples is either remaining in the soil or is partially evaporating during the sample settling time.

Several runs were performed with the ball mill, altering the mixing speeds and mixing times. The gravimetric and UV spectrophotometric results did not show a significant difference in oil recoveries when the mixing speeds and mixing times where altered.

During the stage in the testing when the ball mill was used, the soils tested during these runs contained a greater initial percent of oil than the runs presented in Figure 3. This figure shows the oil recovery percentages obtained using the freon extraction ananlytical method. Using this method the oil recovery percentages ranged from 98.7% to 99.5% for the sand and from 96.2% to 97.8% for the peat.

Figure 4 provides the preliminary results obtained using the ball mill method with hexane as a solvent for removing weathered oil from sand and peat. The results show the oil recoveries obtained using the concentration of oil in the recovered soil found using the freon extraction analytical method.

FIGURE 3: EFFECT OF SOLVENT TYPE AND SOLVENT/SOIL RATIO
ON OIL RECOVERY PERCENTAGES

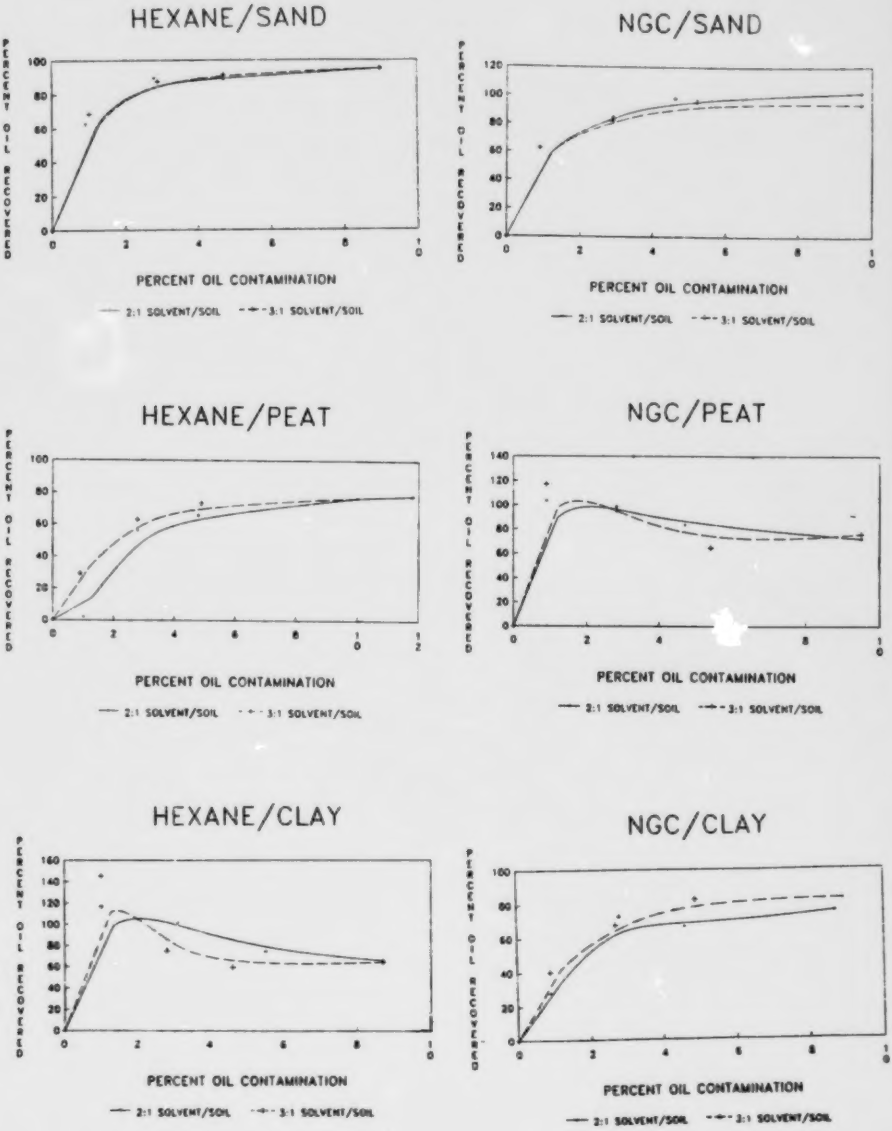
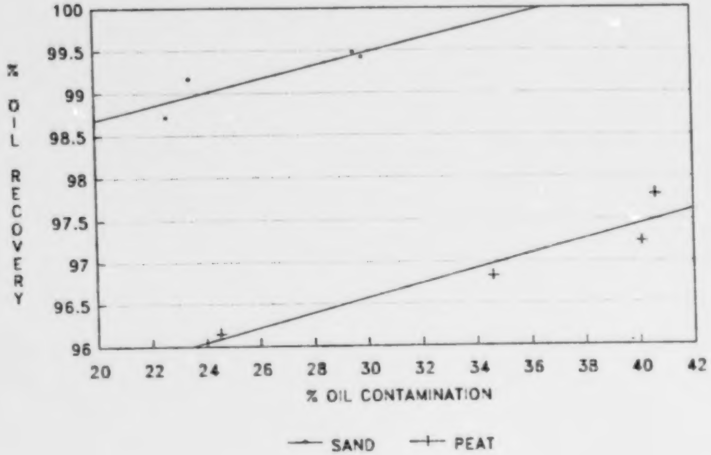


FIGURE 4: WEATHERED OIL - OIL RECOVERY RESULTS
Hexane/soil (wt. ratio) = 2:1



DISCUSSION OF RESULTS

In Figure 3 it can be seen that, for a specific oil contamination percent, hexane and NGC each recovered approximately the same percent of oil from the sandy soil. At oil contaminations of less than 3% the NGC removes a greater quantity of oil, than hexane does, from the peat. At greater than 3% contamination the percent of oil removed from the peat becomes similar for hexane and NGC. The opposite seems to be true for the clay soil where the hexane removes more oil from the clay soil with less than 3% oil contamination. Again the results for removal of oil from the clay at oil contamination greater than 3% gave similar results for the two solvents.

Figure 3 also shows that the greater the initial oil contamination is, the greater the percent of oil recovery is, in all cases except the hexane/clay combination and the NGC/peat combination.

According to Figure 3, when either hexane or NGC is being used with sand, there is no significant difference between using a solvent to soil ratio of two or three. For the hexane/peat and NGC /clay combinations, the solvent to soil ratio of three gave greater percent oil recoveries than the solvent to soil ratio of two. The hexane/clay and NGC/peat combinations showed higher percent oil recoveries for the ratio of three than for the ratio of two. At oil contaminations of about 1% the ratio of two gave higher percent oil recoveries than at oil contaminations greater than 2% by weight. In the cases where the percent oil recoveries are higher for the ratio of three, the increase that occurs, in all cases, is less than 20% and therefore it would be uneconomical to add 50% more solvent in order to remove even another 20% of oil.

The results presented in Figure 4 are for runs where the initial oil concentration was much higher than in Figure 3. The general trend in Figure 4 is that the percent oil recovery increases as the initial oil percent increases, which is similar to the trend shown in Figure 3, using hexane with sand and peat.

The data obtained using the freon extraction method are expected to be more accurate than the gravametric analysis because the freon method utilizes the known initial oil concentration and the final oil concentration, found using freon correlated against spiked samples. The gravametric method relies on weights obtained during the various stages of the extrcation process and performing a mass balance to determine the final oil concentration in the soil. The error introduced with these weights, and the fact that it is difficult to account for the transport of all the mass in the system, causes the gravametric analytical method to be less accurate than the freon analytical method.

FUTURE WORK

The next stage of this project is to optimize the remaining sections of the bench scale process. This will include the centrifuge and the distillation processes. Once the bench scale is constructed, the comparison testing of the hexane and the NGC will continue using simulated contaminated soil samples and actual contaminated soil samples. The sample sizes used in the bench scale process will be approximately 4 times that of the laboratory scale process. More work will be performed comparing the solvent extraction abilities of various distillation fractions of the NGC. Petroleum products, besides light crude oil, will also be used to contaminate the soil samples.

CONCLUSIONS

The evaluations performed to date on the proposed solvent extraction process show that both the natural gas condensate distillate fraction and hexane are effective as solvents for removing oil from contaminated soil and that neither of the solvents have proven to be significantly better than the other.

During the next stage of the project the bench scale process will be assembled and the parameters tested during the laboratory scale portion of the project will be re-evaluated using the bench scale system.

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Raghavan, R., Dietz, D. and Coles, E. "Cleaning Excavated Soil Using Extraction Agents: State of the Art Review" Risk Reduction Laboratory, U.S. EPA, Edison, NJ, June 1988

Development of Arctic River/Delta Boom and Helicopter Towing Techniques for Use in Shallow Water

By Joseph B.H. Smith
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Anchorage, Alaska

Abstract:

In the aftermath of the Exxon Valdez incident, Alaska North Slope oil producers started major efforts to increase their oil spill response preparedness. They began looking for new ways to ensure efficient deployment of their resources, and to identify new equipment needs.

The Alaska Clean Seas Steering Committee targeted the Sagavanirktok (Sag.) River and delta for a spill response exercise in August 1989. The location of the simulated spill would require Endicott, a BP production island directly off the Sag. delta, to protect Howe and Duck islands--the only Snow Goose nesting areas on the north slope of Alaska.

In order to protect the environmentally sensitive areas, it was decided to use a helicopter, towing 1000-ft lengths of containment boom 2 to 3 miles in shallow water, and to deploy the sections in cascading fashion.

Together with the deployment techniques and towing hardware developed for the exercise, a new type of boom was created for use in arctic river deltas and other shallow water areas.

Introduction:

During the 1980s there was very little development of new oil spill containment and recovery equipment. However, as a result of the Exxon Valdez incident and other spills, new oil spill response equipment is being developed at an accelerated rate, and existing hardware is being revamped or modernized.

This paper will present a new technique for deploying boom in the shallow waters of an arctic delta. It will also describe the development, through practical observation and hands-on adjustments, of an improved shallow-water containment/diversion boom.

In early summer of 1989 the North Slope oil producers formalized plans to have a mutual aid oil spill exercise that would involve all the operators to some degree. One of the objectives of the exercise was to identify limitations in the areas of organization, communications, logistics, manpower and equipment.

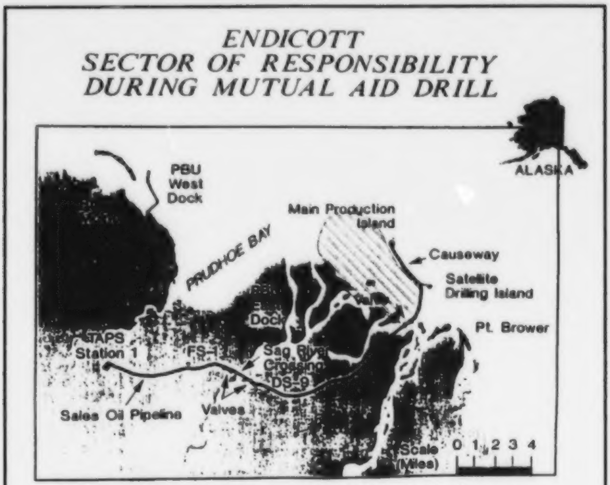
The exercise was to be held on two consecutive Fridays, August 25 and September 1, in order for employees on both shifts to participate. This would also make it likely that there would be two different types of weather for the exercise.

Weekly training periods were scheduled at BP Exploration (Alaska) Inc.'s Endicott facility. A contractor was hired for the training and to assist in preparation of the response gear. On exercise day the contractor's job would be to critique all aspects of the response and to provide recommendations for improvements in techniques and equipment.

The Alaska Clean Seas (ACS) Steering Committee selected the pipeline crossing of the Sag. River as the spill point. A simulated spill of 20,000 barrels during a two-hour release would progress downriver in the westernmost channels of the Sag River. Wind was to be at 15 mph from the northeast, and the current was estimated at 5 fps.

ARCO Prudhoe Bay was assigned the responsibility of overall command. Responsibility for the three sectors was assigned as follows (see Figure 1):

1) River: ARCO Prudhoe Bay and Alyeska Pipeline Service Co.
2) Mouth: BPX Prudhoe Bay
3) Bay: BPX Endicott, ARCO Kuparuk, Conoco, ACS



Endicott area of responsibility (Sector 3) during August 25th and September 1st environmental mutual aid drill

Figure 1

A six-hour field exercise would be followed by a two-hour critique on each exercise day.

BPX Endicott was tasked with the protection of Howe and Duck Islands--the only Snow Goose nesting areas on the North Slope of Alaska--and with diverting the simulated spill, if it reached the bay, to offshore skimming systems brought by sea from West Dock into the Endicott area.

In order to accomplish their mission within the time allotted, and because the water in the delta was very shallow, Endicott decided to try helicopter towing as a means of quickly deploying the boom. During the training sessions on July 14, 15 and 17, a 500-ft section of 8 in x 12 in standard Kepner SeaCurtain boom was towed successfully from the Satellite Drilling Island (SDI) to Duck Island II— about 1,000 yds (see Figure 2).

The aircraft used was a Bell-212. Installed beneath it was a cargo hook with a load capacity of 5,000 lbs. The release mechanism was activated both mechanically and electrically. It was noted during this trial towing that a heavy object was going to be necessary to anchor the leading end of the boom when the pilot released it from the cargo hook. It was also noted that at least two spare helicopter towing lines would be necessary for multiple sorties.

In August, one week before the exercise, 6,000 feet of American Marine Simplex 8 in x 12 in boom was deployed to the northwest end of Howe Island. This pre-deployment accomplished several goals. One was to see how long it took to tow 1000-foot sections of boom from Endicott Island to Howe Island, a distance of two to three miles. A second goal was to give the helicopter pilots a feel for boom towing over distance. Thirdly, the response team members received training in proper ground crew techniques for hooking up and directing the approaching aircraft to a hover point over hook-up area.

Although the tidal variance in the Sag. River delta usually does not exceed 6 inches, wind can cause a difference of up to 18 inches in depth. The prevailing wind is from the northeast; the next prevalent is from the southwest. A northeast wind will push water into the shallow delta areas and river mouths, while a southwest wind will push the water to sea, causing a lot of shallows to be exposed.

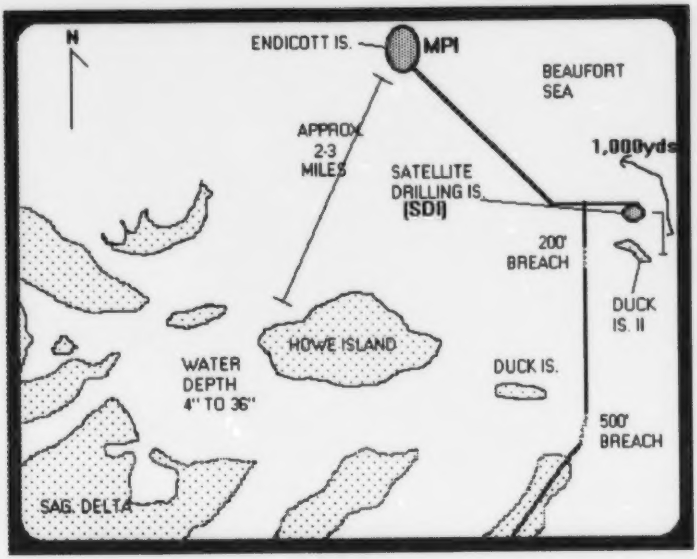


Figure 2

During pre-deployment the wind was from the northeast at 8-12 knots, and the helicopter easily towed each 1,000-ft section of 8 in x12 in boom from Endicott to Howe Island in about 14 minutes. A receiving crew pulled the boom out of the water and faked it down in accordion fashion, so it would be ready for the next deployment. A 25-ft anchor scope line was attached to the boom tow bridle; at the other end of the scope line a "D" ring was attached; then the anchor chain was attached to the "D" ring. This "D" ring was also the point at which the helicopter tow line was attached using a shackle and pin. At the other end of the 125-ft helicopter towing line was another shackle, which would be manually attached to the cargo hook whilethe aircraft hovered in the hookup area. This setup would be used to anchor the leading end as soon as the pilot released the cargo hook catch. (See Figure 5.)

Prior to exercise day, a series of fluorescent orange 18 in diameter marker buoys were deployed from the mainland around the western end of Howe Island and then out into the bay. These buoys were spaced at 900 ft apart and were used as targets to drop the leading end of the tow line and anchor on. Thus the boom could be deployed in a cascading fashion to divert oil around the west end of Howe Island. Two-man crews would then be able to attach to the opposite end of the boom another anchor to keep the boom in place and then smaller anchors every 100 ft to help the boom keep its diverting configuration.

On the day of the exercise, crews were dispatched by helicopter to Howe Island first, then 6,000 ft of boom was deployed and set in approximately 1 hour, 45 minutes. Boats towed 3,000 ft of boom from Endicott to make a cascading string of boom of approximately 8,000 ft from the mainland out past Howe Island's west side and out into the bay where skimming systems and vessels were staged to catch anything that might pass the containment sites upriver (see Figure 3).

Retrieving the boom was more difficult than deploying it. By the next day the wind had shifted and was blowing to the northeast, causing the water to drop in the bay areas and river delta. Boom had to be broken into smaller sections and towed into Howe Island by Suzuki 4x4 ATVs. In the retrieval of the boom across the shallows both by

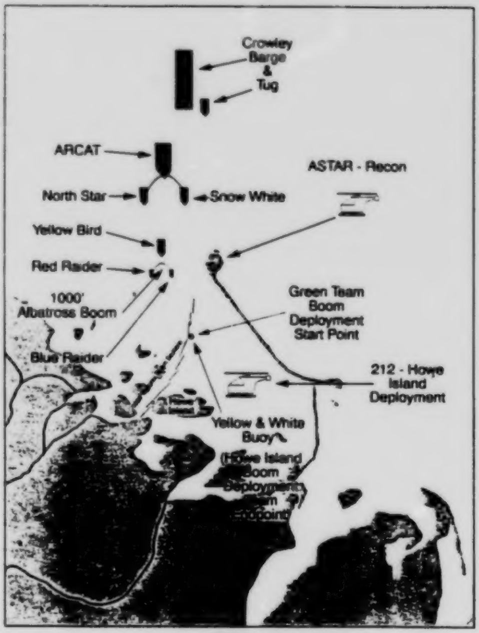

Crowley Barge & Tug
ARCAT
ASTAR - Recon
North Star
Snow White
Yellow Bird
Red Raider
1000' Albatross Boom
Green Team Boom Deployment Start Point
Blue Raider
212 - Howe Island Deployment
Yellow & White Buoy
(Howe Island Boom Deployment Endpoint)

Figure 3

ATV and manually, it was noticed that the boom connectors would scrape the bottom, causing more drag, and after pulling the boom up on the beach and stowing it for the following week's exercise, sand and mud were found to be packed into the the chain pocket, increasing the weight and also the drag when pulling the boom. The extra weight and drag was found to be detrimental the following week in that it caused some boom parts to fail. The connecting ring from the ballast chain to the aluminum boom connector failed because of this extra weight and drag. Some boom failure was noted also, due to there not being enough tow bridles, and having the tow line tied and cinched around the boom just inboard of the connector, which caused the boom to tear from the force exerted on it in the towing mode.

At the critique following each exercise, notes were taken on all aspects of the event; all comments and recommendations concerning the boom deployment were compiled and evaluated. The result was a new type of boom design for

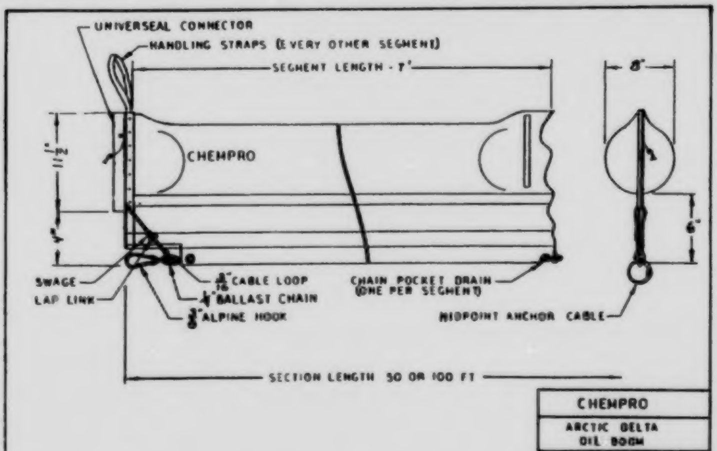

UNIVERSEAL CONNECTOR
HANDLING STRAPS (EVERY OTHER SEGMENT)
SEGMENT LENGTH - 7'
8"
11 1/2"
CHEMPRO
4"
6"
SWAGE
LAP LINK
3/16" CABLE LOOP
1/4" BALLAST CHAIN
3/8" ALPINE HOOK
CHAIN POCKET DRAIN (ONE PER SEGMENT)
MIDPOINT ANCHOR CABLE
SECTION LENGTH 50 OR 100 FT
CHEMPRO
ARCTIC DELTA OIL BOOM
DR. NO: 1029
DATE: 10/2/89
DR. BY: JLP
APP. BY: MJP

Figure 4

Arctic River/Delta Containment Boom

Made in U.S.A. by American Marine, Inc.

Description:	The product consists of a flexible skirt-type oil and debris containment/diversion barrier for inner harbor or protected water use. Especially designed for arctic delta areas and shallow-water helicopter towing.		
Discharge/spill type:	Petroleum products, debris and other floating material.		
How deployed:	From barges, boats, trailers, platforms, helicopters, ATV 4x4's and manually.		
Type of connector:	Universeal aluminum special end connector configuration.		
Compatibility:	Universeal connectors also interconnect with other ASTM connectors.		
Towing speed:	Up to 10 knots without twisting or damage.		
Sweeping speed:	.75 knots	How moored:	Any available means

OPERATING SPECIFICATIONS

Section length:	100 ft and 50 ft	Draft:	6 in
Freeboard:	8 in	Total height:	14 in
Flotation element:	Rolled Microfoam	Flotation shape:	Cylindrical
Flotation length:	6 ft	Flotation width:	8 in diameter
Overall weight:	1.5 lbs/ft	Stowage (vol):	40 cu ft/100 ft of boom
Boom fabric:	22 oz vinyl-coated fabric compounded for a cold crack of -65 ° F.		
Top tension:	5/16 in galvanized steel cable installed in a 1/2-in vinyl tube and seamed into the fabric above the flotation:		
Bottom tension/ballast:	Galvanized 1/4-in chain		
Handling aids:	(1) 2-in diameter drain holes in chain pocket every 6 ft; (2) handling straps big enough for gloved hand every 12 ft.		
Anchoring:	At section connections, by a cable anchor loop through the ballast chain at section midpoint and, if necessary, through the ballast chain at every 2-in drain opening in the ballast pocket.		
Repairability:	Kits are available.		
Cleaning:	Industrial detergents/solvents such as diesel oil, etc.		
Color:	International orange, yellow, red, white, blue, gray, black or green.		

MECHANICAL AND PHYSICAL CHARACTERISTICS

Fire resistivity:	One minute in open flame — does not support combustion.		
Weathering:	5 years in constant use	Fabric strength:	500 lbs per in
Abrasion resistance:	Good	Hydrostatic resistance:	500 psi burst strength
Parting strength:	13,500 lbs		

PERFORMANCE CAPABILITIES

Currents:	Contains oil at approximately .75 knot at 90° to higher velocities at lesser angles.		
Temperatures:	-65° to +140°F.	Stability:	Good
Wind:	15 to 25 knots	Wave height:	3 ft
Conformance to military specs:	Meets MIL Spec - B-28617 (YD)		

Table 1

shallow-water diversion and containment (the same boom could also be effective for diversion in a river-current scenario because of its small draft). The manufacturer made the adjustments to the standard specification sheet, and a new shallow-water boom was born. It was named Arctic River/Delta Boom. (See Figure 4.)

The modifications applied to the new boom were aimed at drag reduction and strengthening the boom longitudinally. For most conditions a 6-in diameter flotation would be sufficient, but a larger (8-in diameter) flotation would provide more splashover protection when choppy water conditions are encountered. The end connectors were shortened from the bottom, and a 5/16-in galvanized steel top cable was installed in a 1/2-in vinyl tube and seamed into the fabric above the flotation. Two-inch drain holes were installed in the chain pocket every 6 ft to allow for water, mud and silt to drain or flush quickly from the chain pocket and handling straps large enough for a gloved hand were installed every 12 ft; this facilitated manually towing and faking the boom down in an accordion pattern. (See Table 1 for specifications.)

Recommendations:

Helicopter deployment of spill response boom can work very well, but must not be relied upon as the primary means of boom deployment. Different pilots were used throughout the training and exercises, and all pilots seemed to master boom-towing techniques without difficulty.

Ground crews who made hookups were best protected with a motorcycle-type helmet with faceshield. Ground signal crews should be equipped with an air-to-ground frequency radio with headset as well as being familiar and competent in the use of hand signals to direct the helicopter in to pickup and drop-off points.

Helicopter boom tow lines should be a minimum of 150 ft in length to mitigate the effects of rotor blade downwash on both the boom under tow and the ground line handler. (See Figure 5.)

Regular containment boom (8 in x 12 in) worked, but the following modifications were made to optimize its performance in deployment, retrieval and cleaning:

1) shorter connector plates : less drag;
2) smaller boom: 8-in diameter flotation, 6-in draft;
3) stronger tension members: towing strength;
4) larger, more visible anchor points: easier mid-point connecting;
5) larger and more numerous handles: easier stowing and handling.
6) 2-in drain holes installed in chain pocket every 6 ft: easier maintenance.

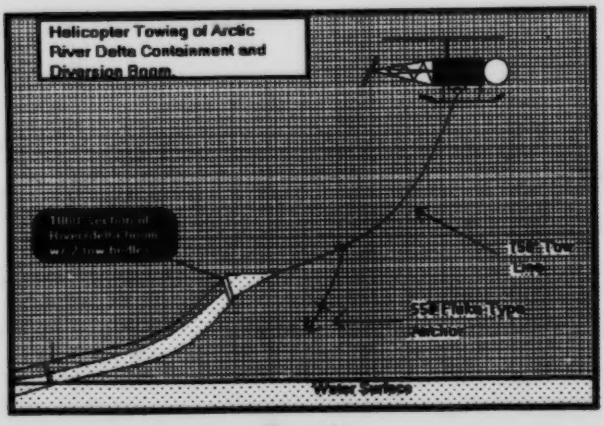

Helicopter Towing of Arctic River Delta Containment and Diversion Boom.
100ft Section of River/delta boom w/ 2 tow bridles
150' Tow Line
55# Fluke Type Anchor
Water Surface

Figure 5

THE DESIGN OF AN INEXPENSIVE FLUME SYSTEM FOR OIL SPILL STUDIES

H.M. Brown, Peter Nicholson, and R. Paterson
Esso Resources Canada Limited

ABSTRACT

A flume system has been constructed in an existing wave basin to provide a venue for oil spill experiments in moving water. The design of the flume is such that it can be assembled quickly and inexpensively and removed after the experiment is completed. It utilizes the existing hydraulic system of the wave generators to power the water pump.

INTRODUCTION

When new oil spill containment, recovery, or removal techniques are developed, they must eventually be tested with spilled oil at a realistic scale. This is often difficult to do at the scale encountered in a real spill because of the costs involved and the reluctance of environmental authorities to deliberately spill large quantities of oil into the environment, even for testing purposes. A reasonable alternative is to conduct such experiments on a smaller but still acceptable scale in a closed environment such as a wave basin. Although the number of such facilities in Canada is limited (Dickens (1989)), many useful experiments have been carried out at these test sites.

In western Canada most oil spills occur on land around producing facilities or where pipelines cross streams and rivers. Facilities in which oil may be spilled in flowing water to test containment and recovery equipment are very few. An additional incentive for building such a facility is the special problem of containing and recovering spilled heavy oil or bitumen from streams or rivers. Thousands of tonnes of this material are produced in northeastern Alberta per day. In one pipeline, about 950,000 m^3 of a bitumen - diluent mixture is shipped from Edmonton to Vancouver each year. This pipeline crosses 450 water courses along its 1000 km length. Equipment and techniques for the recovery of this product, which may become neutrally buoyant within a short time of a spill, need to be tested. This paper describes the conversion of an existing wave basin to a test flume suitable for such experiments.

FLUME DESIGN AND CONSTRUCTION

The Esso wave basin in Calgary has been described previously (Brown et al (1987)). The design concept for the flume was that it be large enough to conduct meso-scale experiments, that it be easily assembled and removed, and that, if possible, the power requirements of the system be met with an existing hydraulic pump. The channel was planned to be 5m wide within the shallow section of the basin which typically contains water about 1 m deep. It was felt that a section of channel 20 m long would be adequate for most experiments. Currents of up to 0.5 m/sec were deemed sufficient as most containment equipment failures occur at flow speeds below this value.

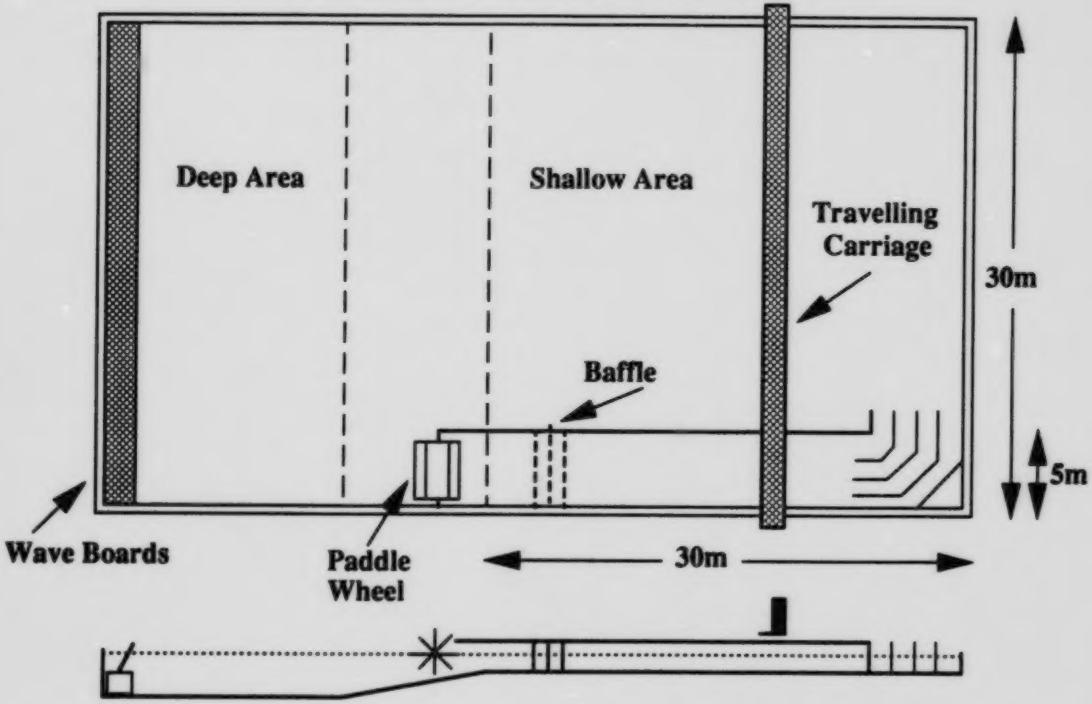
A plan view of the flume as built within the wave basin is shown in Figure 1. A plywood wall was constructed parallel to and 5 m from the south wall of the basin. This was fabricated from pressure treated 8 foot plywood sections mounted on steel angle supports which were attached to the basin floor. Water was driven down the channel by an eight vane paddle wheel mounted on tubular steel supports attached to the basin floor. This unit can be removed in one piece for storage. The paddle wheel was chosen as the water pump after consideration of several alternatives. High volume, low head pumps were very costly and high capacity sludge mixers were rejected because of their generally poor flow profiles. In addition, the paddle wheel was powered with a low cost hydraulic motor which could utilize the existing hydraulic pump installed at the wave basin. The wheel was powered with a 1250 kg-m torque hydraulic motor and had a maximum no load speed of 53 rpm. The wave basin hydraulic pump system was capable of delivering fluid to the motor at 120 l/min @ 210 kg/cm^2. Paddle wheel speed was controlled by varying the fluid delivery rate. These features are illustrated in Figure 2 which shows the paddle wheel and in Figure 3 which is a view up the channel showing both the travelling carriage and the outlet channel partitions.

FLOW TEST

Two types of flow baffles were tested for their effect on the channel current velocity profiles. Initially, a baffle arrangement constructed of treated plywood was used. In this configuration, the water behind the paddle wheel first flowed under a barrier then over a second barrier to drop through ports in the floor of a third - thus traversing an 'S' shaped course. Although this design resulted in good laminar flow, there was significant energy loss between the second and third baffles and the flow was skewed toward one wall. The second and third barriers were removed and replaced by a screen baffle consisting of forty-eight 1.0 metre by 1.5 metre screens held vertically

Figure 1

WAVE BASIN - CHANNEL PLAN


Deep Area
Shallow Area
Travelling Carriage
30m
Baffle
5m
Wave Boards
Paddle Wheel
30m

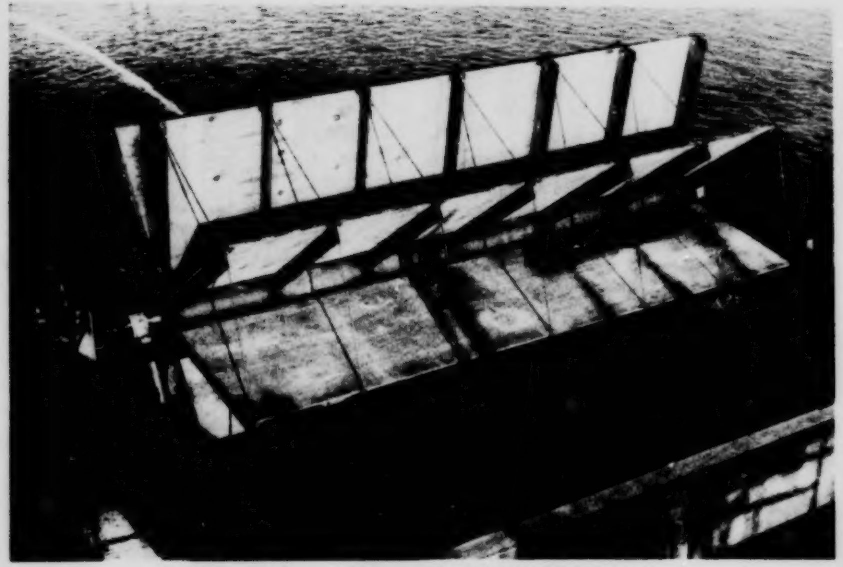


Figure 2 View of paddle wheel and first baffle

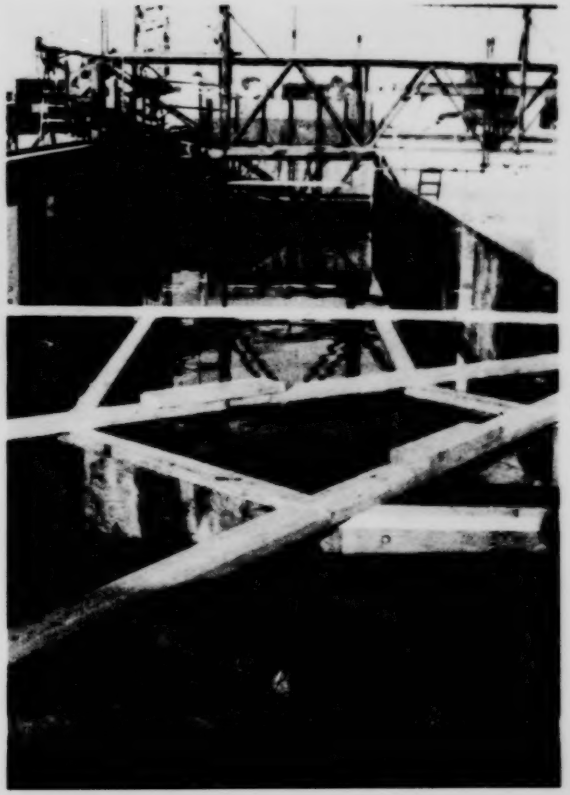


Figure 3
View up channel
showing carriage
and outlet partitions

Figure 4
VELOCITY PROFILE
Solid Baffle Only

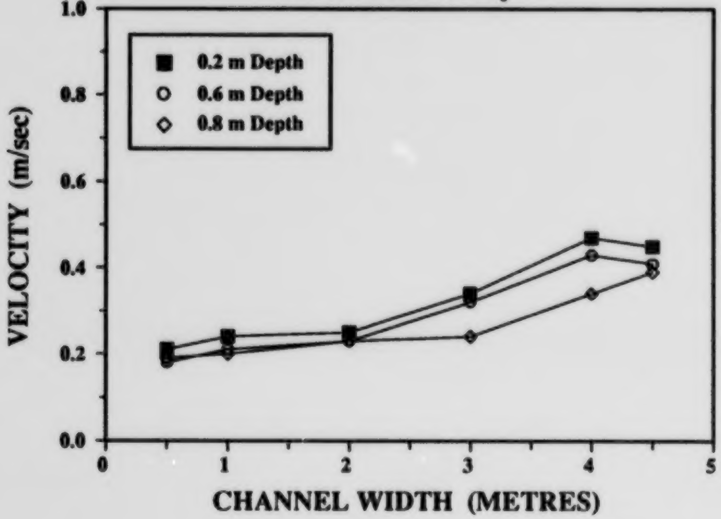
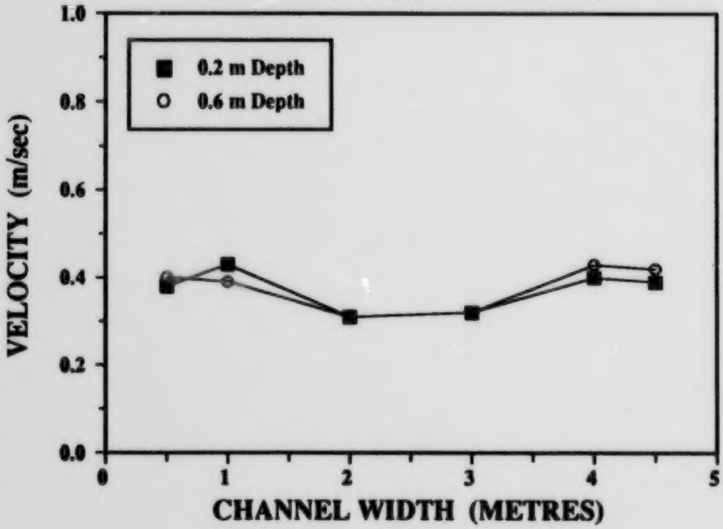


Figure 5
VELOCITY PROFILE
Solid Baffle with Screen Baffle



in the channel and parallel to the flow direction. As can be seen in Figures 4 and 5, this unit helped to straighten the flow profile without reducing the overall flow rate. Flow profiles for different pumping rates were measured using a Price Open Flow meter. The examples shown in the figures were measured 18 metres downstream from the baffles with the paddle wheel pump operating at 10 rpm. The measurements indicate that flow is reasonably uniform over the central 4 m width of the channel and down to a depth of 0.8 m of the total 1 m depth.

The total cost of the materials, construction, and installation of the flume into the wave basin was approximately $30k. This is a very reasonable expenditure given the wide range of experiments planned for this facility.

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DEFLECTION OF OPEN PACK ICE IN AN OIL SPILL RECOVERY AREA

by

Sveinung Løset, Torkild Carstens and Hans Jensen

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Trondheim, Norway

ABSTRACT

Norwegian Offshore Clean Sea Association for Operating Companies (NOFO) is currently running the 4-year research programme "Oil spill countermeasures in arctic waters". As a part of this programme SINTEF NHL has studied the possibility of applying booms to clear the water of broken ice around an offshore structure in the outer marginal ice zone (MIZ) in the Barents Sea. The booms are deployed upstream of the structure. They are kept in place by two suitable vessels each with a towing capacity of 350 kN or more. The system is flexible and allows constant maneuvering of the booms upstream the offshore structure. The deflection of ice allows conventional techniques to be applied in the removal of spilled oil.

1. INTRODUCTION

The particular factors involved in effective handling of oil spills in the Barents Sea devolve from the vulnerability of the environment; the presence of ice, darkness in the winter season and remoteness. The western Barents Sea marginal ice zone (MIZ) is normally composed of distinct ice floes which increase in size with increased distance to the ice edge. The drilling activities in the Barents Sea represent a potential hazard related to possible surface oil spills or subsea and surface blow-outs. The oil spill response capability that may be needed in a few years for these waters does not exist today.

Emphasis in Norwegian oil spill response is placed on controlling the spill, i.e. containment and recovery it as close as possible to its source. Necessary equipment should be operational with booms deployed, skimmers in the water and recovery oil transfer storage assured in 48 hours. To remedy this deficiency a sound next step is to improve the well established oil spill recovery equipment and extend its operational limits to also include parts of the marginal areas in the Barents Sea. The use of flexible booms for deflection of broken sea ice in the oil spill recovery area would ease the application of conventional devices such as oil skimmers and booms during oil spill combat and recovery.

The extension of the application area of conventional mechanical clean-up methods (booms, skimmers etc.) is supplement other strategies such as burning and application of dispersants.

2. DEFLECTION OF ICE

2.1. Concept

The principle of the boom arrangement is shown in Figure 1. The boom is deployed upstream of the offshore structure and is kept in place by two service vessels each with a minimum towing capacity of 350 kN. Such as thruster capacity is typical for anchor handling vessels applied in the North Sea today.

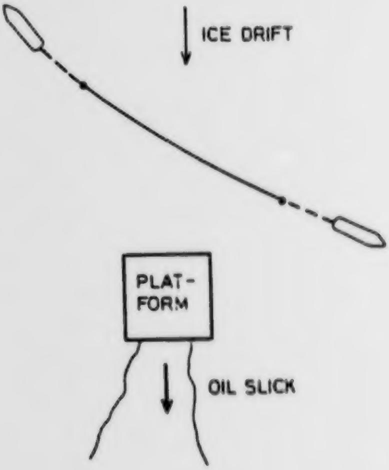


Figure 1. Ice boom arrangement.

The vessels and the ice deflection booms provide a flexible and maneuverable system allowing the booms to be deployed upstream the blow-out and thereby head the prevailing ice drift at any time. This deflection of ice will prevent the ice from mixing with the oil and thereby e.g. enable the use of oil booms and skimmers vulnerable to ice.

2.2. Environmental conditions

The Barents Sea MIZ is normally composed of distinct ice floes. Løset et al. (1989) report the MIZ in the western Barents Sea to typically consist of a relatively narrow edge zone 2-5 km wide. During spring time and after storms brash ice occupies most of the surface area between the distinct floes typically range from 0.5 m to 10 m across. The transition zone starts where the edge zone seizes. In the Barents Sea this zone is often observed to be quite wide, 10-40 km, compared to the Bering Sea MIZ (Bauer and Martin, 1980). The floes of the Barents Sea MIZ are typically 10-40 m across and the zone may be remarkably homogeneous. The interior zone extends from the transition zone and is usually 50-100 km wide. The calliper floe diameter of the interior zone increases typically 4-5 m per kilometre with distance measured perpendicular to the prevailing ice edge (Korsnes, 1988).

The monthly probability for sea ice of different concentrations (C) at 73° 45'N, 19° E is shown in Figure 2. Ice appears only from December to May. The probability is below 8 per cent except for February. The probability of encountering C > 7/10 is at most 3 per cent for February and March.

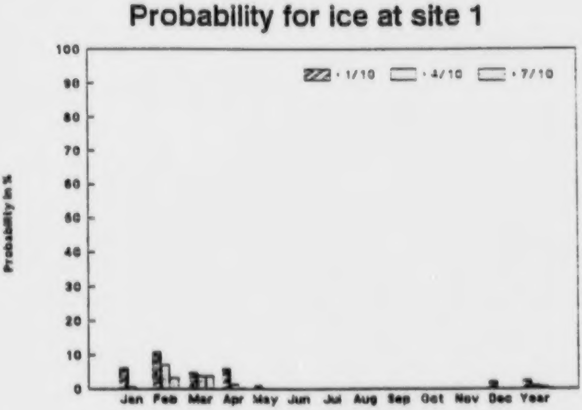


Figure 2. **Annual variation in probability of exceedance for 3 different ice concentrations at 73° 45'N, 19° E (Johannessen and Løset, 1991).**

Another site at 74° 30'N, 22° E is located just on the northern edge of the area expected to be opened for drilling activities in the next years to come. According to Figure 3 ice is encountered from October to June with a maximum probability of about 35 per cent in January, February and March.

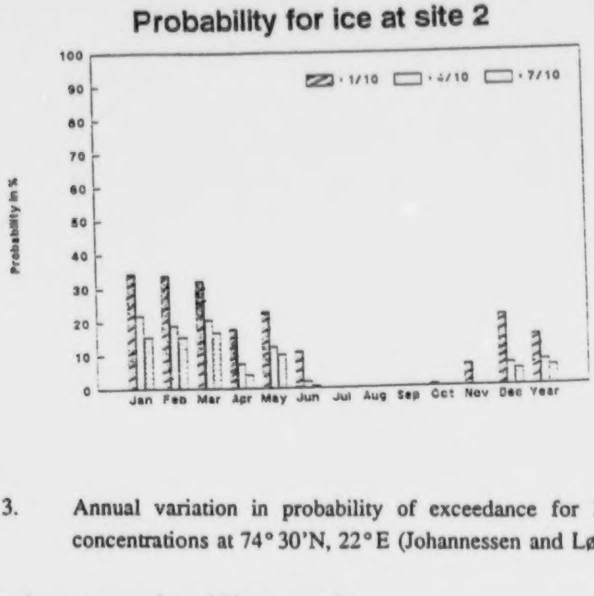


Figure 3. Annual variation in probability of exceedance for 3 different ice concentrations at 74° 30'N, 22° E (Johannessen and Løset, 1991).

2.3. Low ice concentrations (skimmer mode)

The Barents Sea MIZ is normally composed of distinct ice which at the edge may be loosely packed or of a low ice concentration. In such cases the forces exerted on the ice deflection boom is dominated by current forces rather than pressure from the ice. Most of the ice would gather in the down-stream part of the boom as shown in Figure 4. The computations model the ice boom as composed of single elements of 3 m depth and with a total boom length L = 360-460 m. Figure 5 shows the shape of the boom for different distances from the upstream vessel (240-400 kN). In all cases the efficient width of the lead exceeds 200 m.

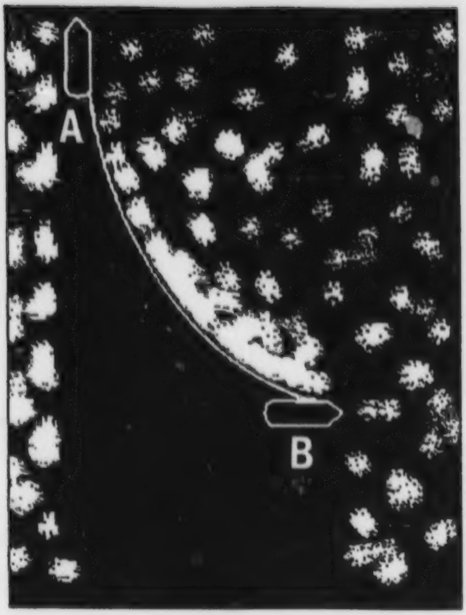


Figure 4. ice boom arrangement for low ice concentrations.

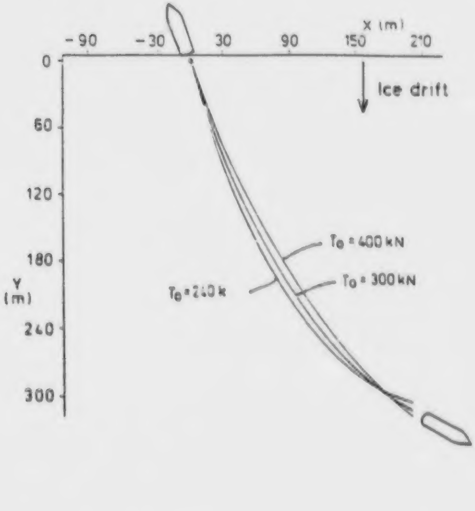
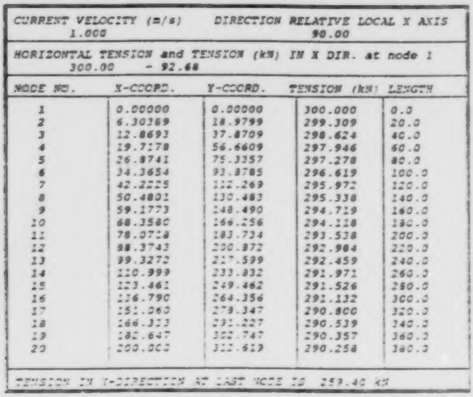


Figure 5. Boom length L = 460 m, current velocity 1.0 m/s and upstream tensions 240, 300 and 400 kN.

Table 1 shows the tension in the boom elements for the case of boom length L = 380 m, current velocity 1.0 m/s and upstream tensions 240 kN.

Table 1. Low ice concentration.
L = 380 m, current speed 1 m/s and upstream tensions 240 kN.



```
CURRENT VELOCITY (m/s)      DIRECTION RELATIVE LOCAL X AXIS
     1.000                              90.00

HORIZONTAL TENSION and TENSION (kN) IN X DIR. at node 1
      300.00     - 92.68

NODE NO.      X-COORD.     Y-COORD.    TENSION (kN) LENGTH

   1          0.00000      0.00000      300.000     0.0
   2          6.30369      18.9799      299.309     20.0
   3          12.8693      37.8709      298.624     40.0
   4          19.7178      56.6609      297.946     60.0
   5          26.8741      75.3357      297.278     80.0
   6          34.3654      93.8785      296.619     100.0
   7          42.2225      112.269      295.972     120.0
   8          50.4801      130.483      295.338     140.0
   9          59.1773      148.490      294.719     160.0
  10          68.3580      166.256      294.118     180.0
  11          78.0728      183.734      293.538     200.0
  12          88.3743      200.872      292.984     220.0
  13          99.3272      217.599      292.459     240.0
  14          110.999      233.832      291.971     260.0
  15          123.461      249.462      291.526     280.0
  16          136.790      264.356      291.132     300.0
  17          151.060      278.347      290.800     320.0
  18          166.333      291.227      290.539     340.0
  19          182.647      302.747      290.357     360.0
  20          200.000      312.613      290.258     380.0

TENSION IN Y-DIRECTION AT LAST NODE IS  259.40 KN
```

2.4. High ice concentrations (plough mode)

For high ice concentrations we expect that Vessel A will be pressed downstream to a position as shown in Figure 6. In the worst case the vessels will be on a line symmetrical to the lead. The boom is filled by ice and a wedge forms upstream.

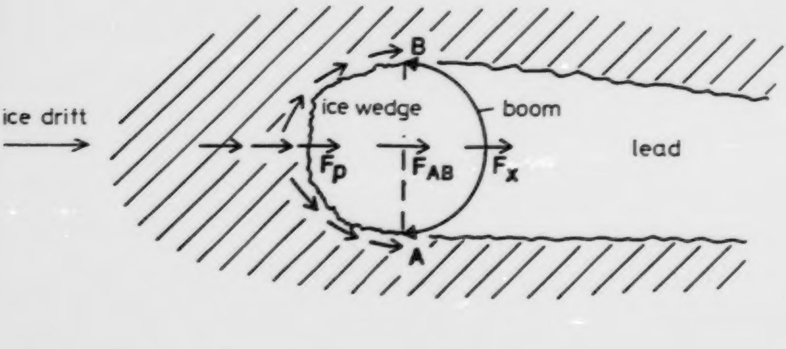


Figure 6. Boom arrangement for high ice concentrations.

A lead can be kept open if

$$F_x \geq F_{AB} \geq F_p \qquad (1)$$

While the force F_x is limited by the depth of the boom and the friction against the boom, ridging may increase F_{AB} so

$$F_{AB} \geq F_p \qquad (2)$$

always is satisfied. A lead is then kept open if

$$F_x \geq F_p \qquad (3)$$

Consider the ice in the wedge as a cohesionless Mohr-Coulomb material with a mobilized friction angle. The maximum force against the ice boom is then ruled by the yield strength which we consider equal the passive pressure

$$\begin{aligned} W &= \frac{1}{2} tg^2(45+\frac{\Phi}{2})(\rho-\rho_{ice})\frac{\rho}{\rho_{ice}}(1-e)gh_k^2 \\ &= kh_k^2 \end{aligned} \qquad (4)$$

where

ρ_w - water density (1025 kg/m^3)
ρ_i - ice density (900 kg/m^3)
e - porosity of the pack (0.7)
g - acceleration due to gravity (9.8 m/s^2)
h_k - ice draft

We consider W to act perpendicular to the boom i.e. the lines of fracture will be parallel to the boom. The force in the ice drift direction reads

$$F_x = \int_L W(\cos\beta + \mu_b \sin\beta)ds \qquad (5)$$

The tangential force is given by

$$\tau = \mu_b W \tag{6}$$

where we consider the normal force to be given by Eq. (4). Table 2 contains the forces involved for a range of friction coefficients μ_b and a boom length of 300 m when $\Phi = 15°$.

Table 2. Forces on the ice boom, L = 300 m.

Friction coefficient boom-ice	0.05	0.1	0.2	0.5
Width of lead (m)	203	202	202	196
F_x (kN)	666	669	756	929
Tension in the middle of the boom (kN)	620	600	570	464

The wedge in front of the ice deflection boom is packed by forces exerted from current and wind. The load on the wedge per meter width, W_p (N/m), is given by

$$W_p = (C_a \rho_a U_a^2 + C_w \rho_w U_w^2) B \tag{7}$$

where

C_w - drag coefficient between ice and air
C_a - drag coefficient between ice and water
ρ_a - density of air (1.3 kg/m^3)
ρ_a - wind velocity (m/s)
ρ_a - current velocity (m/s)
B - ice fetch (m)

The ice velocity is omitted from Eq. (7) since we assume that the ice is retarded to a velocity which is negligible compared to the wind and current velocity. Putting F_x equal to the driving forces on the wedge, Eq. (7), we obtain a relation between the parameters C_a, U_a, C_w, U_w and the characteristics of the ice boom h_k, L, μ_b. Figures 7 and 8 show two examples of such combinations.

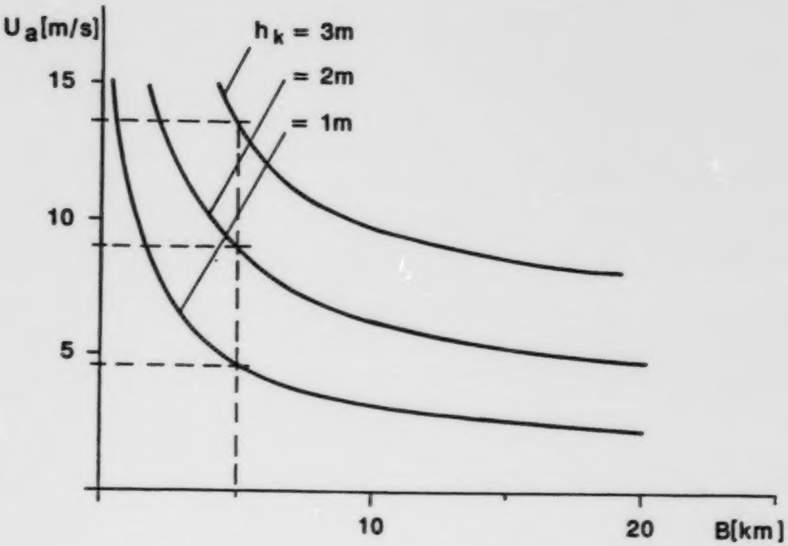


Figure 7. Capacity of the ice deflection boom for an ice belt 5 km wide with C_w=5·10^{-3} and μ_b=0. D = 1 m and U_w=0.17 m/s, D = 2 m and U_w=0.34 m/s, D = 3 m and U_w=0.51 m/s.

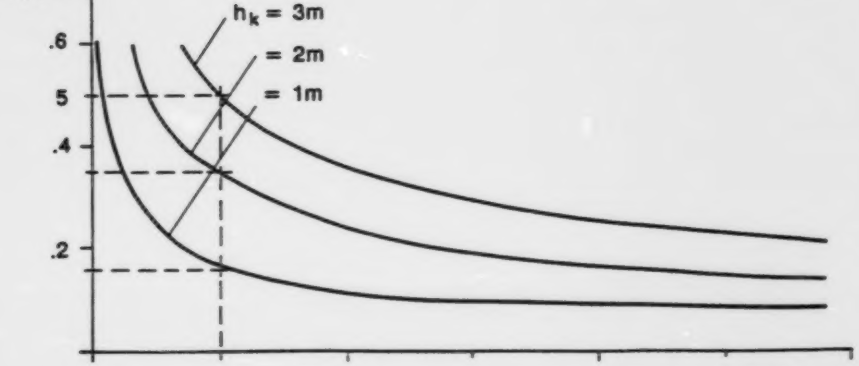


Figure 8. Capacity of the ice deflection boom for an ice belt 5 km wide with C_w=5·10^{-3} and μ_b=0. D = 1 m and U_w=4.6 m/s, D = 2 m and U_w=9.2 m/s, D = 3 m and U_w=13.8 m/s.

2.5. Dynamic loading from single ice floes

The ice deflection boom may also be exposed to dynamic loadings from single big ice floes. The floe is supposed to drift towards the boom and upon hitting the kinetic energy of the floe is absorbed until it comes to rest and possibly passes the boom (see Figure 9). Considering an ice floe with drift speed v the kinetic energy reads

$$E_k = \frac{1}{2} m v^2 + \frac{1}{2} m \omega_0 \left(\frac{i^2 r^2}{i^2 + r^2} \right) \tag{8}$$

where

m - mass including added mass
ω_0 - angular velocity
r - radius of the floe
i - radius of inertia

E_k is expressed by the first term on the right hand side of Eq. (8) when assuming $\omega_0 = 0$. A conservative displacement of the boom is readily computed when we disregard sliding along the boom (see Figures 10-11).

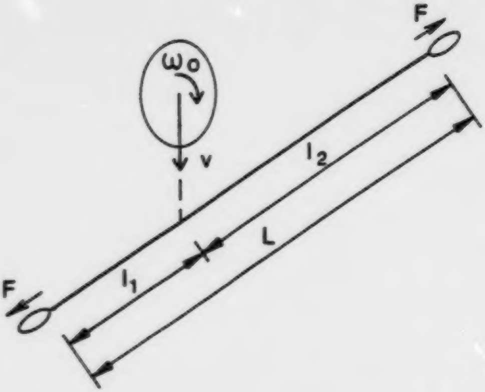


Figure 9 Dynamic impact from a single ice floe.

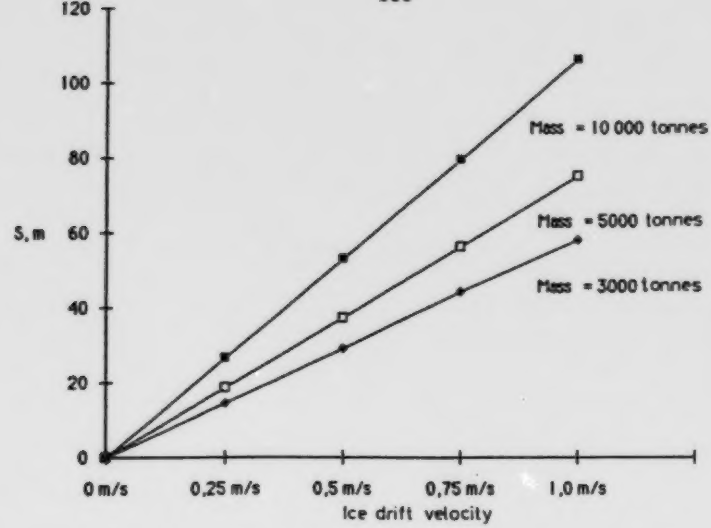


Figure 10. Displacement of the boom, L = 380 m.
Towing force: 300 kN.

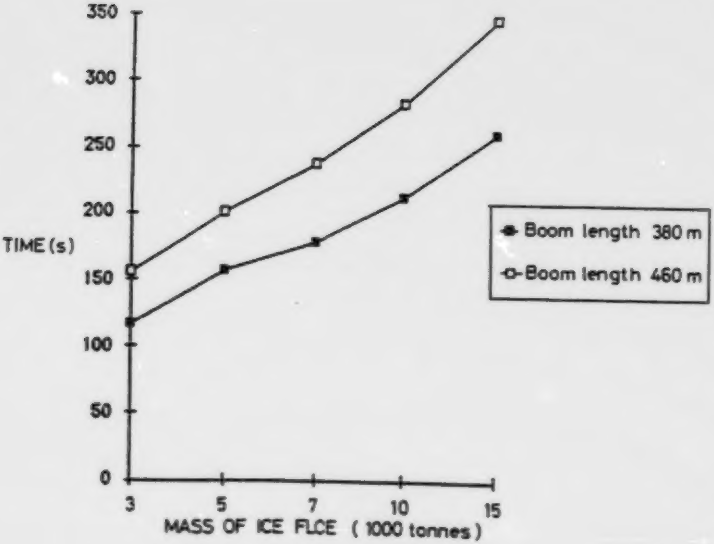


Figure 11. Time consumption for stopping floes of different masses.
Towing force: 300 kN.

3. DISCUSSION AND CONCLUSIONS

Mechanical equipment for oil spill clean-up may be applied in the marginal ice zone in the Barents Sea. This is made possible by applying a flexible boom deployed upstream the spill site between two towing vessels.

In case of low ice concentrations (C < 3/10) the ice deflection boom is deployed with an angle which deviate about 45° from the prevailing drift direction of the ice field. Under these conditions the ice is deflected without any special ice load exerted on the boom. The boom is exposed to current forces which mainly are directed perpendicular to the boom. Vessels with a towing capacity of 300 kN or more are sufficient to keep the ice booms in place. The towing force can also be reduced by applying a design of the boom which allows water to flow through the booms. To provide a lead of 200 m width, the length of the boom should be 300-400 m.

For high ice concentrations (C > 3/10) the ice deflection boom may form an arc filled of ice with an upstream ice wedge. The boom will be exposed to perpendicular and tangential forces which are derived from current and wind forcing of the ice. There is no direct current forcing on the boom.

Ice can be stopped when using booms of 300 m length and a depth equal to the draft of the ice. The towing capacity which is required is proportional to the squared draft of the ice and depends strongly of the friction between boom and ice. For pack ice about 2 m deep a towing capacity of 300 kN is sufficient. However, the vessel itself is exposed to ice loads and the maneuverability in pack ice is considerably hampered. A typical anchor handling vessel applied today in the North Sea has a towing capacity of 300-400 kN. Hence it is unlikely that such vessels are capable of handling this deflection device in ice concentrations of e.g. 5/10.

Single ice floes will be retarded by forces exerted form the towing vessels via the ice boom. Ice floes with considerable size and speed can be stopped. As an example a floe of 10000 tonnes with an initial drift speed of 1 m/s can be retarded by two towing vessels each with a capacity of 300 kN. The displacement is estimated to 110 m.

The horizontal extension of the plume in the case of underwater blow-outs is not considered (Fanneløp and Sjøen, 1980). This may of course reduce the efficiency and applicability of the method. The vessel-boom configuration must also respond to changes in current direction. This requirement to maneuverability and boom handling needs to be evaluated before the method can be declared feasible.

4. REFERENCES

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SHORE-ZONE MAPPING SYSTEM FOR USE IN SENSITIVITY MAPPING AND SHORELINE COUNTERMEASURES

by

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ABSTRACT

An electronic database was developed for the BC physical shoreline classification to (1) store shore-zone data, (2) manipulate data for use in oilspill response planning and (3) provide a GIS compatible database for use in integrated resource management. The system includes a schema for coding shore-zone data and models for derivation of coastal types, oil residence indices and shoreline treatment options.

Initial mapping was at a scale of approximately 1:20,000 and involved subdivision of the shoreline into alongshore units and across-shore components; features in the range of 10m (length or width) are mapped. Both information on substrate and morphology are included. A hierarchial classification system is used to summarize the repetitive shore-zone types. Thirty one repetitive coastal types were used to categorize coastal character; this classification is based on substrate, texture, shore-zone width and slope. The classification can be systematically reduced to a smaller number of shore types depending on the desired application.

An objective Wave Exposure Index (WXI) was developed to minimize subjective judgement of wave exposure. The WXI is based on measurements of effective fetch and maximum fetch.

The shore-zone database, classification system and wave exposure index were carefully developed to interface with a Shoreline Oil Residence Index that defines sensitivity in terms of how long oil might remain within the coastal zone. The system also interfaces with a Shoreline Cleanup Manual developed separately by the Province.

Advantages of this system are: (a) the high degree of detail recorded, sufficient for operational planning activities; (b) GIS compatibility to facilitate data recovery and manipulation; (c) a hierarchial classification system that can be summarized at different scales as appropriate and (d) a wave exposure and shore zone classification system that minimizes the use of subjective interpretation.

INTRODUCTION

Statement of the Problem

The southern Strait of Georgia and bordering San Juan Islands have been identified as a high risk area for oilspill potential by a number of studies (Wolferstan, 1980; Anderson, 1989; States/British Columbia Task Force on Oil Spills, 1990; Brander-Smith, 1990). As a result of the high risk associated with spills in this area, the Province of British Columbia has initiated several projects to improve oilspill response capabilities. These projects include: (a) establishment of an Environmental Emergency Branch to focus attention on oilspill risk, (b) review of environmental data sources for the area, (c) collection and editing of aerial videotapes and (d) assessment of the role of GIS systems for environmental atlases and oilspill response. This study builds on these projects by providing a physical framework for environmental resource inventories and by categorizing physical oilspill sensitivity (i.e., potential oil residence) of the shoreline.

Objectives

The overall goal of the study is to provide a systematic characterization of shore-zone morphology of the Strait of Georgia for use as a framework for characterization of the biological resources of the shore-zone and assessment of oilspill sensitivity.

Specific objectives of the study are:

(1) development of a GIS-compatible database for recording shore-zone information,

(2) standardization of the various mapping and coding systems that have been used within the proposed project area,

(3) provision of a "quality assurance" review to bring all existing data to a common standard,

(4) categorization of the shore-zone character and oil residence indices for future use in oilspill planning and response.

Project Area

The project area is outlined in Figure 1 and estimated to include in excess of 1,000km of shoreline.

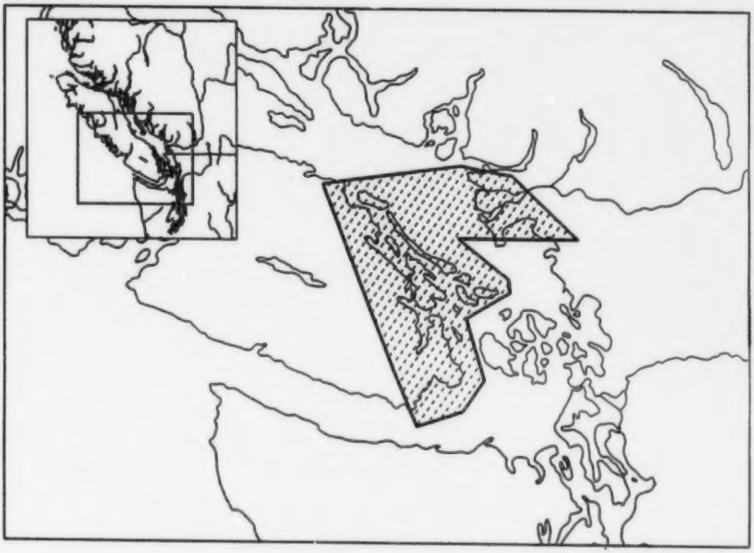

Figure 1. Southern Strait of Georgia Study Area

TECHNICAL APPROACH

Overview

The mapping program is described in terms of four components as follows:

> **Mapping** - this involved (a) the development of a data schema for the BC Physical Shorezone Classification system (modified Howes and Owens, 1979) for electronic storage of physical resource data, (b) the review of an existing shore-zone mapping data (Romaine, 1982 a & b) and the application of standards prior to data entry and (c) development of a classification models to summarize data for use in sensitivity, countermeasure and integrated resource management applications.
>
> **Wave Exposure Evaluation** - this component of the study involved the development of a Wave Exposure Index (WXI) to objectively categorize wave exposure characteristics of each coastal unit. Wave exposure is a critical factor controlling biological community structure and potential oil residence, and as such, is a key factor in the evaluation of spill sensitivity.
>
> **Oil Residence Index** - the Oil Residence Index (ORI) is an estimation of how long oil might remain in the shore zone, and is normally dependant on substrate type and wave exposure. Permeability is also important in estimating ORI but requires *in situ* field measurements. The ORI was estimated from the mapping and wave exposure data.
>
> **Shoreline Treatment Options** - shoreline countermeasures, including protection cleanup strategies were evaluated as part of a sperate study (Cramer and Owens, 1991). However, the shoreline classification system was incorporated into the strategy such that a fully integrated mapping and countermeasure evaluation is possible.

The final product of the program, an integrated GIS Resource and sensitivity analysis, remains to be completed. However, the approach illustrates how the various components can be isolated, developed and eventually integrated to form a comprehensive product. An interim, hard-copy atlas is expected in 1991 and a completed GIS contingency plan anticipated in 1992.

Mapping

The data schema used is a modified form of the physical shore-zone survey coding format (Howes and Owens, 1979; Howes and Lewis, 1984). This system divides the shoreline into discrete units, using a primary, secondary and variant methodology.

The information in the resource folios (Romaine, 1982 a & b) which are the main source of information for the project, are compatible with this approach.

The database management program (CODAT) is configured on an IBM based computer system using the dBase III+ programming language. The database structure (SHORDAT) is in the form of two separate, linked databases (Table 1). A "general" database contains all relevant information on a unit by unit basis. A second, "linked" database, is used to code all information at the sub-unit level.

Because a principal objective of this project was to provide a high quality data set for the study area, standards were established for (a) review of the existing data (Quality Assurance) and (b) transfer of information to the electronic database (Quality Control).

The Quality Assurance refers to our evaluation of the original data. The original data was compared to Ministry of Environment aerial video imagery to check for interpretation variations. In that the aerial video imagery was not available for the entire shoreline and the imagery varied significantly in quality, the Quality Assurance applied to the project area is not presently to a common standard. The following summary indicates variance in Quality Assurance levels:

Video Imagery Quality	Geographical Locations
High (boulder to cobble-sized features generally distinguishable)	Vancouver Is Coast: Race Rocks to Nanaimo (see exceptions below); Saltspring Island
Moderate (image quality ranging high to poor) frequent long-pans, particularly to heads inlets and bays.	Gabriola Is; DeCorcy Group; Thetis Is; Kuper Is; Valdez Is; Prevost Is; Galiano Is; Boundary Bay
Low (images very poor; long-range pans frequently 0.5 to 1 kilometer to HWL)	Fraser Delta
None (no imagery available)	Race Rocks; Trial Is; Chatham and Discovery Is; Mayne Is; Saturna Is; North and South Pender Is; Scott Is; Hudson Is; Parker Is; Wise Is; Charles Is; Reid Is; Hall Is; Secretary Is; Portland Is; Moresby Is; "Saanich Is" (all islands east and north east of Saanich Peninsula)

TABLE 1 DATABASE USED IN THE COASTAL MAPPING SCHEMA

Linked Database #1 (General)

- REGION*
- AREA*
- UNIT*
  - LENGTH
  - NTS*
  - SCALE*
  - START LOCATION
  - END LOCATION
  - MAPPERS*
  - DATE MAPPED*
  - EDITORS*
  - DATE EDITED*
  - DATA SOURCES*
  - GROUND TRUTH
  - TIDES*
    - TYPE*
    - LARGE RANGE*
    - MEAN RANGE*
  - FETCH
    - MAXIMUM DIRECTION
    - MAXIMUM LENGTH
    - SHORE NORMAL
    - LEFT 45
    - PERPENDICULAR
    - RIGHT 45
    - EFFECTIVE FETCH
    - WAVE EXPOSURE
  - REFERENCES
    - VIDEO NUMBER*
    - AIRPHOTO NUMBER

Linked Database #2 (Shoreline)

- SUB-UNIT* (along shore physical units from data sets)
  - CLASS* (see section 3.0)
  - TYPE* (original coded type: primary, secondary, etc.)
  - LENGTH
  - SEDIMENT TRANSPORT
    - SOURCE
    - ABUNDANCE
    - DIRECTION
  - SHORELINE CHANGE
    - TYPE
    - RATE
  - FORESHORE USE
  - ZONE* (across shore, back-shore, intertidal)
    - COMPONENT*
      - FORM* (descriptive morphology)
      - MATERIAL* (sediment description)
      - WIDTH* (where included in the data set)
      - SLOPE
      - PROCESS
  - OIL RESIDENCE INDEX

In keeping with the general descriptive nature of the mapping system, descriptive terms for Coastal Class, a summary indicator of morphology, are preferred. The rational for classifying the shoreline is illustrated in Table 2; this illustrates the 32 Coastal Classes resulting from a four component classification.

There is a tradeoff between complexity of the Coastal Classes (e.g., Table 2) and the desire to summarize or simplify information. However, Table 2 was used to assign Coastal Class as the greater number of types allows greater flexibility in selection of derivative classifications at a later date.

Wave Exposure Index

Calculation of wave energy or wave exposure for a given shore point is a highly sophisticated procedure involving consideration of the fetch distance, fetch window, wind climate and nearshore slope. As a first approximation, wave fetch is commonly used as an indication of wave exposure. There are, however, different means of calculating fetch and the influence of fetch windows. There is also the complicating factor of swell that may have been generated in a different area but have propagated into the area of interest.

The method used for the British Columbia CODAT mapping program is to use a modified version of **effective fetch** (U.S. Army Corps of Engineers, 1977). Because of the highly crenelate nature of the British Columbia coastline, a "**modified effective fetch**" was developed as an index of wave exposure. The modified version involves only three measurements for each reference shore station (shore normal fetch; fetch at 45° to the right of the shore normal, fetch 45° to the left). Several comparisons indicated less than a 10% difference between the computed effective fetches and the "modified" effective fetch. This "modified" effective fetch provides an excellent first approximation of wave exposure for restricted fetch areas such as the Southern Strait of Georgia.

As mentioned above, there is the additional complication of swells that are generated outside the local area but contribute to the wave energy at the shore. An index of this potential swell component is provided by recording the azimuth and distance of the maximum fetch. Where maximum fetch distances are significantly greater than the "modified" effective fetch, the Wave Exposure Index is increased. Table 3 contains a proposed Wave Exposure Index for use in British Columbia.

The Wave Exposure Index is automatically calculated from the fetch data entered into the database, although the fetch measurements were not included as part of this project.

TABLE 2 THE FOUR COMPONENT COASTAL CLASSIFICATION

SUBSTRATE	SEDIMENT	WIDTH	SLOPE	COASTAL CLASS
ROCK	n/a	WIDE (>30m)	STEEP(>20°)	n/a
			INCLINED	(5-20°Rock Ramp, wide (1)
			FLAT(<5°)	Rock Platform, wide (2)
		NARROW (<30m)	STEEP(>20°)	Rock Cliff (3)
			INCLINED(5-20°)	Rock Ramp, narrow (4)
			FLAT(<5°)	Rock Platform, narrow (5)
ROCK + SEDIMENT	GRAVEL	WIDE (>30m)	STEEP(>20°)	n/a
			INCLINED(5-20°)	Ramp w gravel beach, wide (6)
			FLAT(<5°)	Platform w gravel beach, wide (7)
		NARROW (<30m)	STEEP(>20°)	Cliff w gravel beach (8)
			INCLINED(5-20°)	Ramp w gravel beach (9)
			FLAT(<5°)	Platform with gravel beach (10)
	SAND & GRAVEL	WIDE (>30m)	STEEP(>20°)	n/a
			INCLINED(5-20°)	Ramp w gravel & sand beach, wide (11)
			FLAT(<5°)	Platform w G&S beach, wide (12)
		NARROW (<30m)	STEEP(>20°)	Cliff w gravel/sand beach (13)
			INCLINED(5-20°)	Ramp w gravel/sand beach (14)
			FLAT(<5°)	Platform with gravel/sand beach (15)
	SAND	WIDE (>30m)	STEEP(>20°)	n/a
			INCLINED(5-20°)	Ramp w sand beach, wide (16)
			FLAT(<5°)	Platform w sand beach, wide (17)
		NARROW (<30m)	STEEP(>20°)	Cliff w sand beach (18)
			INCLINED(5-20°)	Ramp w sand beach, narrow (19)
			FLAT(<5°)	Platform w sand beach, narrow (20)
SEDIMENT	GRAVEL		WIDE (>30m)	n/a
		NARROW (<30m)	STEEP(>20°)	n/a
			INCLINED(5-20°)	Gravel beach, narrow (21)
			FLAT(<5°)	Gravel flat or fan (22)
	SAND & GRAVEL	WIDE (>30m)	STEEP(>20°)	n/a
			INCLINED(5-20°)	n/a
			FLAT(<5°	Sand & gravel flat or fan (23)
		NARROW (<30m)	STEEP(>20°)	n/a
			INCLINED(5-20°)	Sand & gravel beach, narrow (24)
			FLAT(<5°)	Sand & gravel flat or fan (25)
	SAND/MUD	WIDE (>30m)	STEEP(>20°)	n/a
			INCLINED(5-20°)	Sand beach (26)
			FLAT(<5°)	Sand flat (27)
				Mudflat (28)
		NARROW (<30m)	STEEP(>20°)	n/a
			INCLINED(5-20°)	Sand beach (29)
			n/a	
	ORGANICS/FINES	n/a	n/a	Estuaries (30)
ANTHROPOGENIC	MAN-MADE	n/a	n/a	Man-made, permeable (31)
				Man-made, impermeable (32)

TABLE 3 WAVE EXPOSURE INDEX

Maximum Fetch (km)	"Modified" Effective Fetch (km)				
	<1	1-5	5-50	50-500	>500
<5	v low	n/a	n/a	n/a	n/a
5-10	low	low	n/a	n/a	n/a
10-75	moderately low	moderately low	moderate	n/a	n/a
75-750	moderate	moderate	moderately high	high	n/a
>750	n/a	n/a	n/a	v high	v high

Oil Residence Index

A summary of the factors controlling potential oil residence and their combined influence on oil residence are shown in Table 4; this table relates Coastal Classes and Wave Exposure to potential oil residence periods. The estimates are based largely on authors' observations from the EXXON Valdez shoreline oiling. Sediment permeability and sediment mobility are also important in controlling oil residence but require field evaluation; for purposes of this project, they are assumed to be indirectly related to physical shore-zone character and wave exposure.

Based on the estimates from Table 4, five Oil Residence Categories are defined:

Oil Residence Index	Estimated Oil Residence Period
1	days to weeks
2	weeks; weeks to months
3	weeks to months
4	months; weeks to months; months to years
5	months to years

TABLE 4 OIL RESIDENCE ESTIMATES

EXPOSURE	SUBSTRATE	TEXTURE	MOBILITY	OIL RESIDENCE
	Rock	n/a	n/a	days to weeks
		Gravel	Mobile Immobile	weeks to months months
HIGH	Rock & sediment or sediment	Gravel & sand	Mobile Immobile	weeks weeks to month
		Sand	Mobile	weeks to months
	Man-made	Impermeable Permeable	n/a n/a	days to weeks weeks
	Rock	n/a	n/a	weeks to months
		Gravel	Mobile Immobile	months to years months to years
MODER-ATE	Rock & sediment or sediment	Gravel & sand	Mobile Immobile	months months to years
		Sand	Mobile	weeks to months
	Man-made	Impermeable Permeable	n/a n/a	weeks months
	Rock	n/a	n/a	weeks to months
		Gravel	Immobile	months to years
LOW	Rock & sediment or sediment	Gravel & sand	Immobile	months to years
		Sand	Mobile	months to year Immobilemonths
	Man-made	Impermeable Permeable	n/a n/a	weeks months to years
		Estuaries	fine/organics	Mobilemonths to years Immobilemonths to years

Note: Underlining indicates more probable oil residence within a range

These Oil Residence Categories (above) were entered into a matrix relating the Wave Exposure Index and Coastal Class (Table 5); the matrix was included as a separate routine in the database and the Oil Residence Index was automatically calculated for each subunit.

In practice, there are actually only seven types of coastal morphology that are considered in the oil residence estimates because (a) rock & sediment substrates are treated the same as sediment and (b) gravel & sand are treated the same as sand. As such, the following categorization is used to develop the Oil Residence Index:

1. Rock	(Classes 1,2,3,4,5)
2. Gravel	(Classes 6,7,8,9,10,21,22)
3. Sand	(Classes 11,12,13,14,15,16, 17,18,19,20,23,24,25,26,27)
4. Mud	(Class 28)
5. Estuary	(Class 30)
6. Man-made (perm.)	(Class 31)
7. Man-made (imp.)	(Class 32)

Shoreline Treatment Options

As mentioned previously, a shoreline Clean-up manual was developed as part of a separate project for the Ministry Environment (Cramer and Owens, 1991). The manual describes countermeasure options for the different coastal types identified in Table 1.

RESULTS

The results are described in terms of the mapping results and oil residence estimates. Summaries are provided in terms of the percentage of units mapped because the actual shoreline mileage will not be available until completion of the GIS mapping.

Shore-zone Types

The relative distribution of repetitive shoreline types within the project area is indicated in Table 6. The summary is based on the analysis of subunit coastal class.

The distribution is relatively evenly divided between categories of rocky coast (37%), such as sediment-free rock cliffs and ramps, rock and sediment coasts (27%), such a rock cliffs or platforms with beaches, and sediment coasts (34%), such as sand and gravel beaches. Less than 5% of the coast is anthropogenic in origin. The two most common coastal types are narrow rock cliff shores (12%) and wide (>30m) sand and gravel beaches (11%).

TABLE 5 OIL RESIDENCE CATEGORIES

COASTAL CLASS	Wave Exposure High	Mod.	Low
1. Rock Ramp, wide	1	2	4
2. Rock Platform, wide	1	2	4
3. Rock Cliff	1	2	4
4. Rock Ramp, narrow	1	2	4
5. Rock Platform, narrow	1	2	4
6. Ramp w gravel beach, wide	3	4	5
7. Platform w gravel beach, wide	3	4	5
8. Cliff w gravel beach	2[1]	4	5
9. Ramp w gravel beach	3	4	5
10. Platform with gravel beach	3	4	5
11. Ramp w gravel & sand beach, wide	4	4	5
12. Platform w G&S beach, wide	4	4	5
13. Cliff w gravel/sand beach	4	4	5
14. Ramp w gravel/sand beach	4	4	5
15. Platform with gravel/sand beach	4	4	5
16. Ramp w sand beach, wide	3	3	4
17. Platform w sand beach, wide	3	3	4
18. Cliff w sand beach	3	3	4
19. Ramp w sand beach, narrow	3	3	4
20. Platform w sand beach, narrow	3	3	4
21. Gravel beach, narrow	4	4	5
22. Gravel flat or fan	4	4	5
23. Sand & gravel flat or fan, wide	3	3	5
24. Sand & gravel beach, narrow	3	3	5
25. Sand & gravel flat or fan, narrow	3	3	5
26. Sand beach, wide	3	3	4
27. Sand flat	3	3	4
28. Mudflat	n/a	n/a	2
29. Sand beach, narrow	3	3	4
30. Estuaries	n/a	n/a	5
31. Man-made, permeable	2	4	5
32. Man-made, impermeable	1	1	2

---

[1] assume mobile sediment

TABLE 6 SUMMARY OF COASTAL CLASS FREQUENCY OF OCCURRENCE

	Coastal Class	No. of Units	Percentage of Total	
	1	118	6%	
	2	90	5%	
ROCK	3	216	12%	
	4	167	9%	
	5	95	5%	37%
	6	16	1%	
	7	35	2%	
	8	47	3%	
	9	66	4%	
	10	23	1%	
	11	49	3%	
	12	120	7%	
ROCK & SEDIMENT	13	24	1%	
	14	26	1%	
	15	39	2%	
	16	7	0%	
	17	11	1%	
	18	7	0%	
	19	13	1%	
	20	1	0%	27%
	21	85	5%	
	22	6	0%	
	23	202	11%	
SEDIMENT	24	129	7%	
	25	15	1%	
	26	39	2%	
	27	68	4%	
	28	25	1%	
	29	22	1%	
	30	26	2%	34%
MAN-MADE	31	43	2%	2%
		1,830	100%	

Oil Residence Index

The frequency of occurrence of Oil Residence Index Categories is provided below:

Oil Residence Index	Estimated Oil Residence Period	No. of Units	Percentage of Total
1	days to weeks	454	25%
2	weeks; weeks to months	113	6%
3	weeks to months	641	35%
4	months; weeks to months; months to years	584	32%
5	months to years	25	2%

As one would expect from the relatively low wave exposure and common occurrence of gravel or sand & gravel shorelines, relatively lengthy oil residence would be expected within much of the study area; approximately 70% of the study area is considered to have potential oil residence periods of greater than a few weeks. Given the intensive recreational and subsistence use of the shore zone in this area, it is likely that a large proportion of the shoreline would require treatment in the event of a spill.

CONCLUSIONS

Conclusions are presented in terms of those related to system development and those related to the preliminary results.

1. The data entry program (CODAT) will promote a standardized coding and data entry of the physical shore-zone classification system in future projects.

2. The electronic database (SHORDAT) will facilitate manipulation and transfer of data for multiple use.

3. The database provides for cost-effective data analysis for integrated and oilspill-related applications.

4. The database and system have been incorporated within the Ministry of Environment Oil Spill Response Information System (OSRIS).

5. The system will facilitate access to detailed information for site specific locations in the event of a spill.

6. The summary of potential oil residence indicates that a significant portion of the project area would likely require treatment in the event of a spill.

APPENDICES

We gratefully acknowledge the support of the British Columbia Ministry of Environment, Environmental Emergency Branch for this project.

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WHEN LESS IS BEST--THE DILEMMA OF ACCURATE MAPPING

by

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Canada

One of the major criteria used for determining the extent of shoreline oiling is the length of the shoreline. While this would seem to be an easy parameter to determine, this is not the case. The length of the shoreline is a function of the resolution with which the shoreline is measured. This leads to the situation where poor measurement techniques will result in the reduction of the length of shoreline contamination. This problem will be discussed and a proposal presented which will allow the resolution of this quandary.

INTRODUCTION

In the reporting of an oil spill incident, numbers play a critical role and are frequently misinterpreted. In many cases, the larger the number, the more important the incident. This results in the selective choice of units, for example a 10,000 cubic metre spill would seem much smaller than the equivalent 10,000,000 litre spill. The amount of effort to clean-up a spill and the apparent impact of the spill are frequently judged by the size of the spill. The amount of compensation is frequently based on spill statistics. One example of this is the amount of shoreline oil as the result of a spill. While the numbers game with units is used for this statistic, there is another problem of the resolution to which the shoreline is mapped. The statement ***"100 kilometers of shoreline has been oiled"*** has an imprecise meaning unless the resolution of the mapping is stated, or is implicitly understood by the writer and the reader of the text.

A LESSON IN SIMPLE GEOMETRY

The measurement of shoreline length is a function of the resolution of the measurement as can be seen from figure 1. If one assumes a headland to headland measurement, the total amount of shoreline would be D. If the shoreline were divided into N elements, the total amount of shoreline would be multiplied by the form factor, as shown in Figure 2. If each of these elements is subdivided into a further

N elements, the apparent length would increase by another amount of the form factor. For a single level of modulation, the shape with an infinite number of sides, that is the semi-circle, has a form factor of pie (3.14). While this may seem to involve a significant change in length, as the resolution is increased, the apparent increase in length is inversely proportional to the resolution for an infinitely rough shoreline. This means that changing a mapping scale from 1:1,000,000 to 1:100,000 would increase the shoreline length by a factor of 10, if the resolution of the mapping is proportional to map scale. If it is not, then the necessity for the smaller scale map should be questioned.

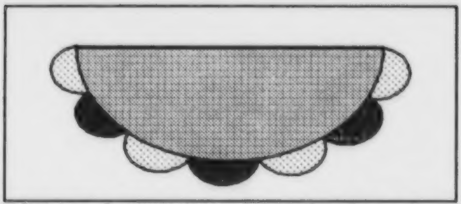

Figure 1 Overlapping circles show the effects of resolution on shoreline length

Form Factors for Various Shapes

Shape	Form Factor
Triangle	2.00
Square	3.00
Semi-Circle	3.14

Figure 2 Form factors for simple geometries

It is obvious from this discussion that there are only two answers to the question ***"How much shoreline has been oiled?"*** are ***"An infinite amount"*** or ***"That question cannot be answered"***. Neither of these answers is satisfactory, so a more precise method of answering the question must be developed. This added criterion is directly related to mapping resolution and the practical aspects of surveying shoreline oiling.

SPECIFICATION OF SHORELINE LENGTH

A suggested way out of this dilemma is to use a standard chart or mapping scale to determine the amount of shoreline oiling. A 1:50000 would probably be the best compromise between a high-resolution map and acceptable coverage for an area.

CONCLUSIONS

In order to properly define shoreline length, it is necessary to state the scale or resolution of the measurement. Thus when specifying shoreline oiling length, care must be taken to state the scale at which the measurements are reported.

NEW CAPABILITIES IN REAL-TIME OIL SPILL AND FATE PREDICTION USING HF RADAR REMOTE SENSING

by

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1.0 INTRODUCTION

In times of emergency response to oil spills at sea, accurate prediction of the motion and fate of the floating slick is desirable. Over the continental shelves the surface circulation is notably variable, responding to tides, winds, density variations and low-frequency shelf waves. Much of this variability is not predictable with present numerical models or from available oceanographic data, and as a result slick motion projections tend to become quickly inaccurate. As with weather forecasting, ocean current prediction would benefit greatly from real-time data, either to be used directly in spill motion calculations, or for assimilation into circulation models.

At this time, HF radar remote sensing techniques provide the only practical means of obtaining surface current maps that cover enough of the shelf seas to be useful for spill motion modelling, at an acceptable accuracy and cost. Following a brief review of this measurement technique, some recent advances in new instrumentation and its use in emergency response to spills are discussed in this paper.

2.0 BACKGROUND TO HF RADAR

Over 35 years ago Crombie (1955) first explained the strong, distinctive symmetric peaks observed in HF sea-echo Doppler spectra in terms of Bragg scatter from surface waves. Crombie (1972) also suggested the use of these peaks to deduce surface currents, and devised an experiment utilizing a direction-finding two-element antenna pair to sense the magnitude and direction of the Gulf Stream flow off Cape Kennedy, Florida. The radial speed was related to bearing direction through the phase differences between the two antenna elements at each Doppler spectral frequency in the Bragg peak echoes.

In the absence of currents, the Bragg mechanism produces sea echo peaks that appear at Doppler positions proportional to the phase speed of waves whose lengths are exactly half the radar wavelength. For a given radar frequency, usually between 6 to 26 MHz, the wave length is known, and the reference position of these peaks can be precisely calculated. Any underlying radial component of current near the surface at the point of scatter will impart an additional shift from the reference position that is converted to speed through the Doppler relation.

The surface waves producing the echo are essentially tracers for the water current, analogous to turbulent scatterers in water that produce the return signal sensed by subsurface acoustic Doppler current profilers. Upper HF radar frequencies are selected since they scatter from short waves with periods of about 3 s; there is almost always some energy in these waves, even under the calmest conditions.

Under conditions of vertical current shear near the surface, waves are transported by the current at a mean depth equal to the radar wavelength divided by 8π. For example, at 12 MHz the mean depth is 1 m and the total layer thickness that influences the current is about 2 m. Thus the HF radar accurately measures horizontal currents in the uppermost layers, where other instruments such as current meters and acoustic doppler profilers become inoperable. For this reason, the HF measured currents are ideal for oil motion prediction.

The Bragg scatter mechanism yields information on current variations radial to the radar (i.e. pointing away from or toward the radar). Thus, two sites must view a point on the water in order to produce an unambiguous estimate of the total horizontal current vector. HF radar signal formats (pulse or linearly swept frequency) employ time delay to isolate the return from a annular segments of ocean at different radial distances from the coast (Fig. 1a). Two methods are generally employed to isolate the scattering patch in bearing: beam forming and direction finding (DF) methods.

HF current-sensing systems that employ DF methods have become known as CODARs (Lipa and Barrick, 1973), and feature compact antenna systems with three or four elements. The newest version, called SeaSonde, packages the entire receiving antenna system in a unit about 25 cm square containing a monopole and crossed-loopsticks (Fig. 1b).

In 1988 a CODAR system was used in a major demonstration project to map currents off the west coast of Vancouver Island (Dunbar et al., 1989) for the federal Department of Fisheries and Oceans. Current meter and drogue data, used to validate the radar measurements, demonstrated that the radar current maps were generally accurate to within 4-8 cm/s (Hardy et al., 1989). This level of accuracy meets the requirements for many oceanographic applications, and the spatial current maps yielded new and important information on surface current features never seen before, with important implications for fisheries research, oil spill response and maritime search and rescue.

CODAR
Coastal Ocean Dynamics Applications Radar

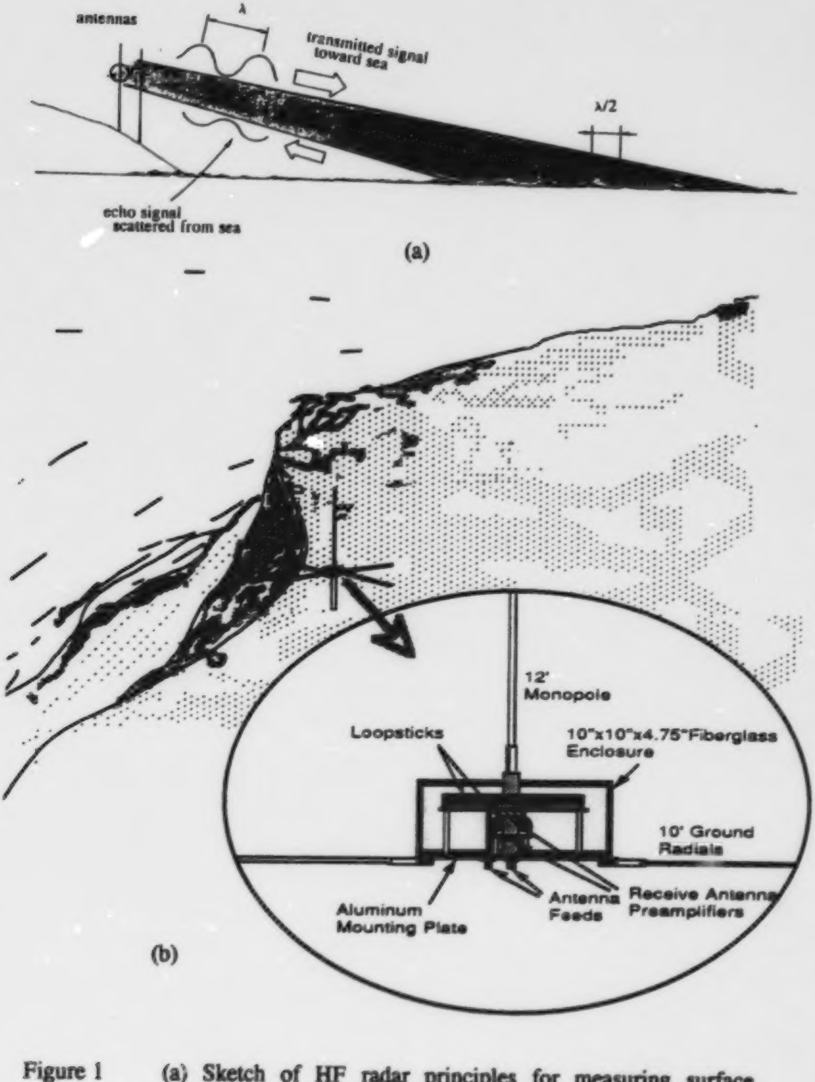

antennas
λ
transmitted signal toward sea
λ/2
echo signal scattered from sea
(a)
12' Monopole
Loopsticks
10"x10"x4.75"Fiberglass Enclosure
10' Ground Radials
Antenna Feeds
Receive Antenna Preamplifiers
Aluminum Mounting Plate
(b)

Figure 1 (a) Sketch of HF radar principles for measuring surface currents, (b) the crossed-loop receiving antenna system used at 12 MHz for the SeaSonde.

3.0 REAL-TIME SURFACE CURRENTS FOR OIL SPILL MODELLING

3.1 A Spill Hindcast Using HF-sensed Currents

Late in October and early November, 1988, two radar stations were established at Pachena and Carmanah Points, on Vancouver Island, to measure currents over Swiftsure Bank, at the entrance to Juan de Fuca Strait. These radars were the older form of CODAR employing a 4-element square receiving antenna. The transmit frequency was 25.4 MHz and the radial ring spacing was 1.2 km. A DF algorithm (Hardy et al., 1989) was used for deriving surface currents. Hourly surface current maps were obtained for several days.

An example of one current map is shown in Fig. 2, indicating the strong tidal flows along the coast out of the strait. It also shows a distinct front over the edge of the shelf where the outflowing brackish water merges with the oceanic water. The offshore range of this radar was about 35 km, and the data are shown here on a 2 x 2 km Cartesian grid oriented EW-NS. An oil spill model (Hodgins et al., 1991) was implemented on the 500-m Cartesian grid shown in Fig. 3, and a hypothetical spill of about 20,000 m^3 was released over 6 hours off the mouth of Juan de Fuca Strait.

The hourly radar surface current maps were used to drive the oil spill model. In order to extend the radar coverage area to the total model grid domain, a simple interpolation and filling algorithm was applied to the radar data (Fig. 4). These fields were subsequently interpolated onto the 500-m grid for the oil spill model using bilinear interpolation.

The evolution of the spill at 1, 2, 3 and 6 hours after release is shown in Fig. 5. The currents at 5 and 11 hours after the spill are plotted in Fig. 6. As can be seen here the tidal influence is strong in this area, producing a constantly changing flow pattern. The distinct zone of convergence at 11 hours is a characteristic tidally-induced feature recurring in the maps over several days. The spill is mapped at 9 and 12 hours in Fig. 7; the convergence in surface flow between these times has resulted in a reduction of the area occupied by the spill.

3.2 Real-time Spill Motion Prediction

The second-generation CODAR systems, called SeaSondes offer several significant improvements over the older units, the most important of which are increased range (up to 70 km); compact, solid-state RF electronics for greater reliability; compact, easily deployed antenna systems; VHF data communications between sites and real-time vector map processing; PC-based data acquisition and processing; and a user-friendly graphical user interface for data display and manipulation. The entire RF and data acquisition system is packaged as shown in Fig. 8, and the equipment is suitable for rapid deployment during emergency response. A data-link

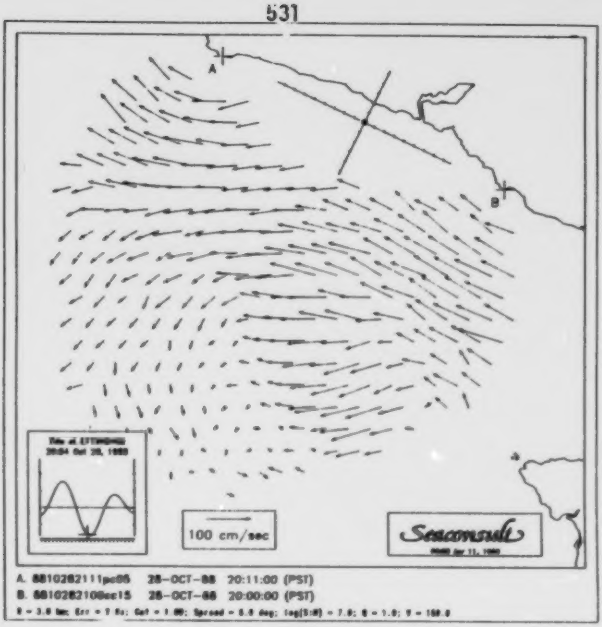

A
B
100 cm/sec
Seaconsult
A. 8810282111pc05 28-OCT-88 20:11:00 (PST)
B. 8810282100ec15 28-OCT-88 20:00:00 (PST)

Figure 2 Surface currents over Swiftsure Bank off Vancouver Island measured using HF radar.

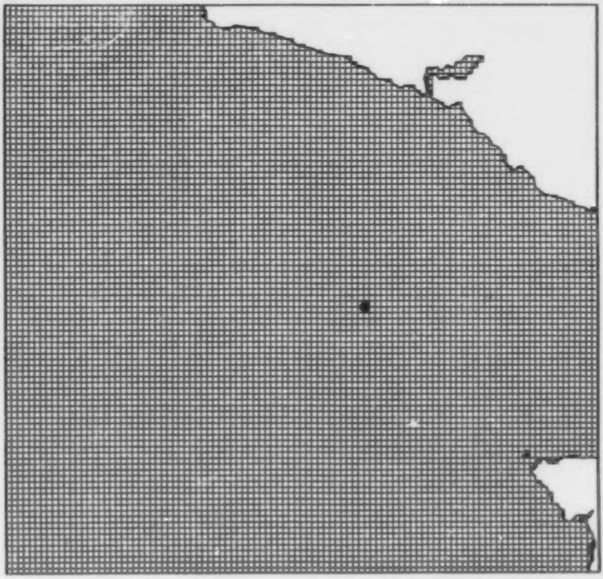


Figure 3 Model grid with a 500-m spacing for oil spill modelling off the mouth of Juan de Fuca Strait.

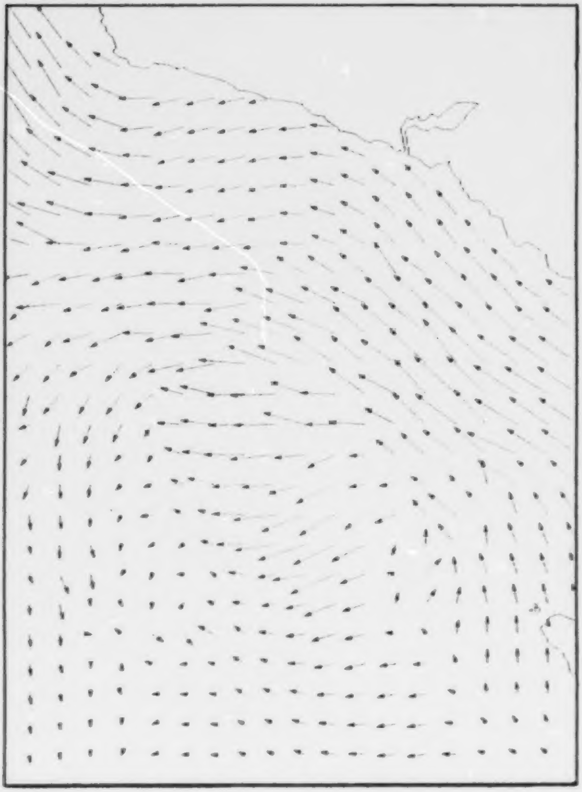


Figure 4 Extended surface current field incorporating the HF radar sensed currents.

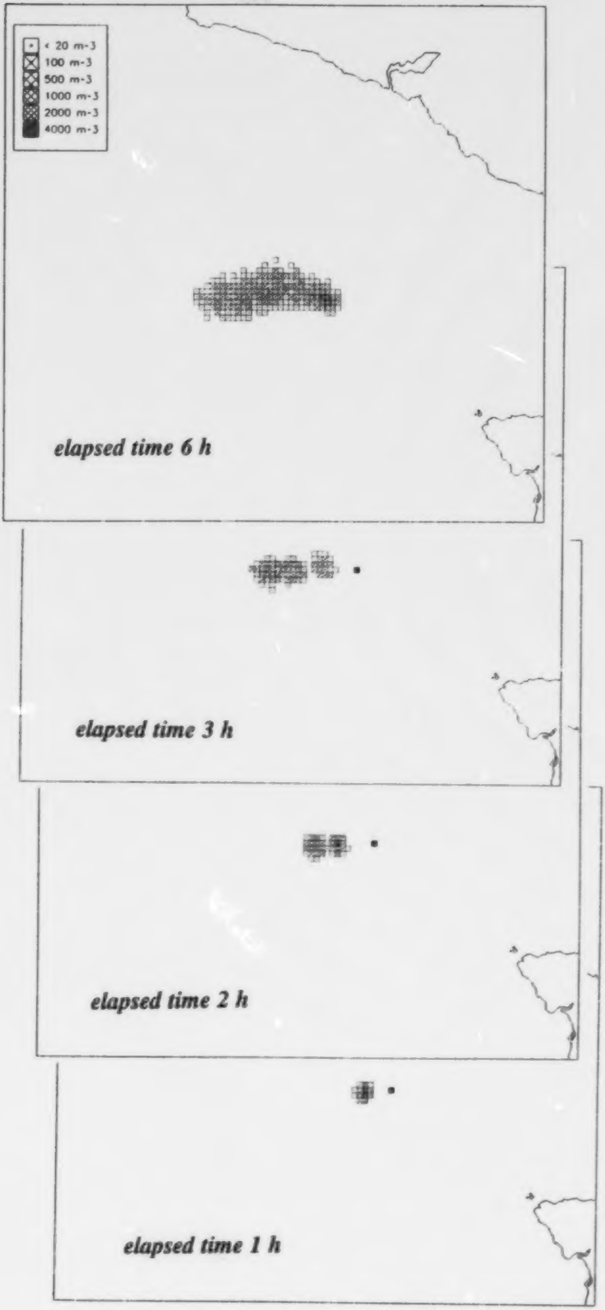
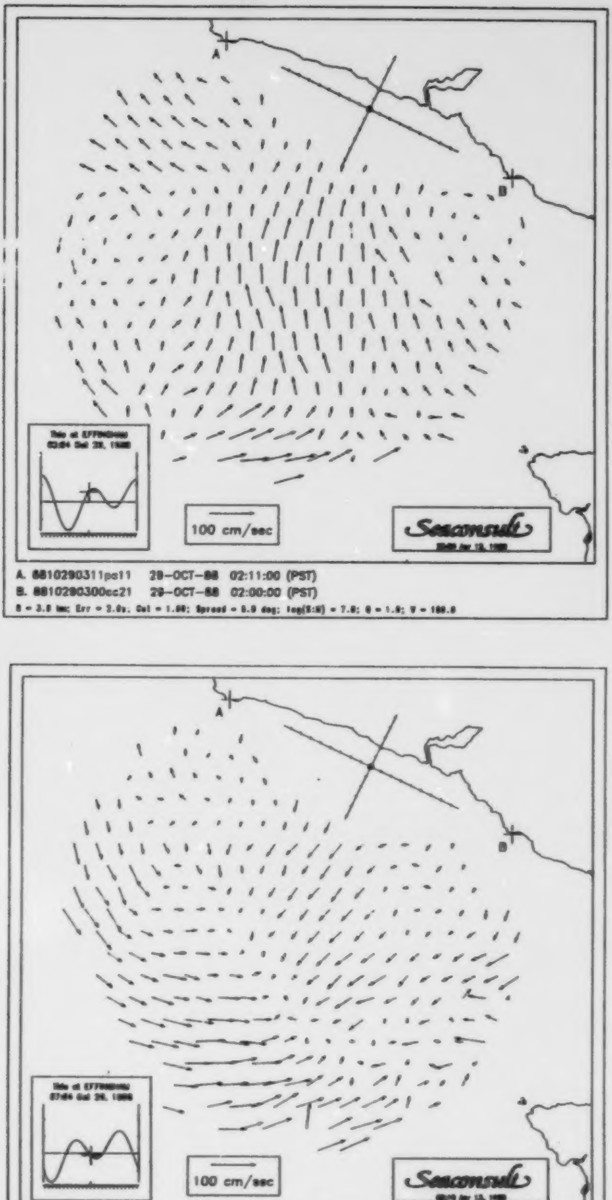

< 20 m-3
100 m-3
500 m-3
1000 m-3
2000 m-3
4000 m-3
elapsed time 6 h
elapsed time 3 h
elapsed time 2 h
elapsed time 1 h

Figure 5 Evolution of a 20,000 m^3 crude oil spill using measured surface currents to calculate the motion.


A
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A
B
100 cm/sec
Seaconsult
A. 8810290811pc18 29-OCT-88 07:11:00 (PST)
B. 8810290800cc26 29-OCT-88 07:00:00 (PST)

Figure 6 Surface currents measured with HF radar at elapsed times of 5 and 11 hours after the spill started.

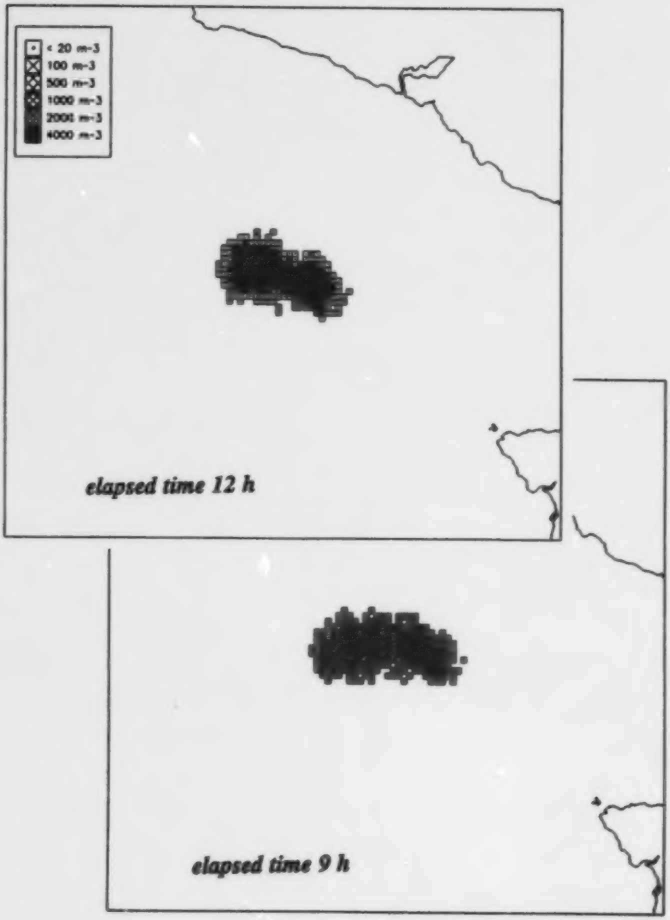
< 20 m-3
100 m-3
500 m-3
1000 m-3
2000 m-3
4000 m-3
elapsed time 12 h
elapsed time 9 h

Figure 7 Modelled slicks 9 h and 12 h after the spill time, showing the reduction in slick size resulting from convergent flows.

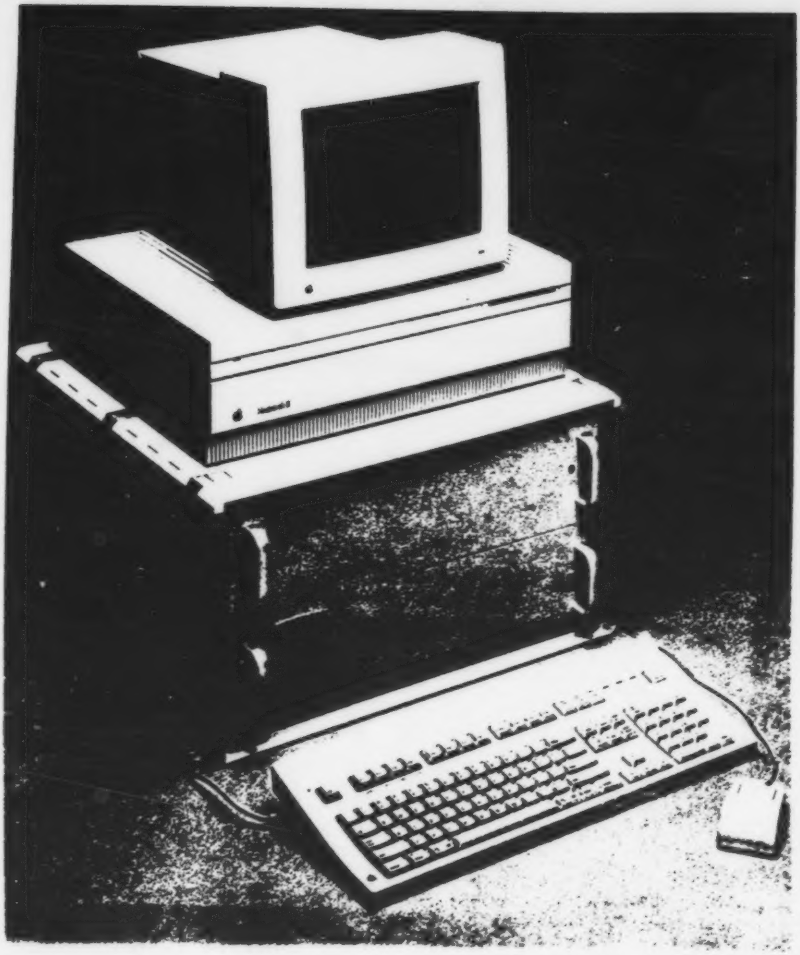

Figure 8 Photograph of the SeaSonde system for coastal current mapping out to 70 km range. All radar hardware except the antenna is contained in the lower box. The data acquisition and processing is performed by the Macintosh II computer.

between the radar central site computer, an oil spill model and a geographic information system could be easily established.

The conceptual system combining surface currents obtained in real-time with an HF radar and information on the distribution of oil is shown in Fig. 9. Two forms of oil spill motion prediction are envisaged: (1) short-term monitoring wherein the surface currents are used directly to update the position of the slick on an hour-by-hour basis; and (2) longer-term forecasting for 36 to 48 hours. The forecasting procedure would involve accumulation of HF-sensed surface current maps with automatic re-analysis for tidal harmonic constants and non-tidal current components. As the number of maps increases in the database, the analyses would account for more of the variance in the current fields. The analyses results could also be assimilated into various databases or models for shelf circulation and wind-driven currents.

Forecasting the slick motion would then make use of the tidal harmonics, and the other information on low-frequency currents, in conjunction with meteorological forecasts and wind-driven current models, to give the expected future motion. The key to success in this type of forecasting lies in accurate, site-specific current data acquired with the radar system.

4.0 CONCLUSIONS

Extensive ground-truthing of CODARs in the U.S., Canada, and Germany over the past 15 years has established their accuracy for remote sensing surface currents. The improvements in the new SeaSonde indicate that the technology is now ready for rapid deployment in emergency response, and provides information on surface circulation features that are both unobtainable by any other means, and important for accurate motion prediction. The user interface designed for SeaSonde also provides the data handling, display and analysis capabilities required for interfacing with oil spill models.

5.0 REFERENCES

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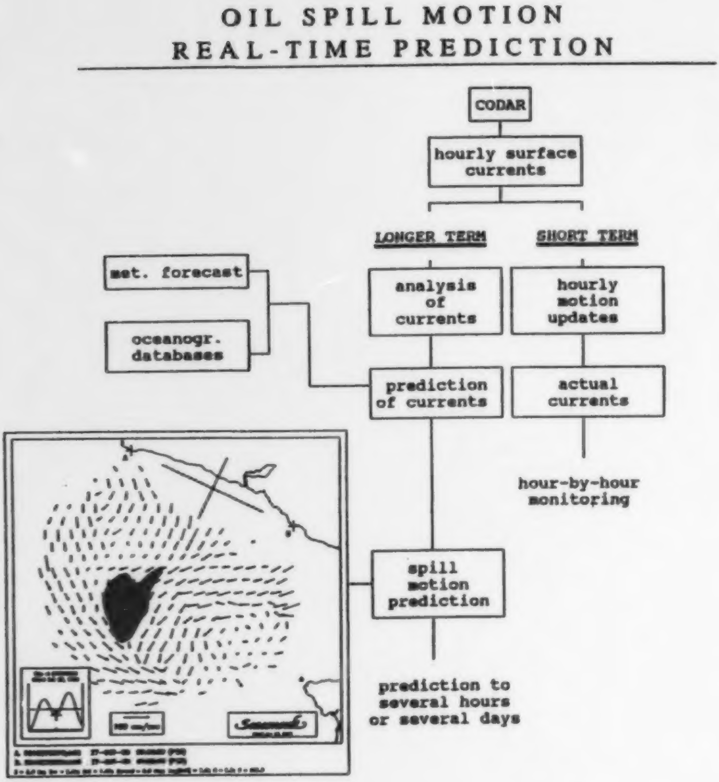
OIL SPILL MOTION
REAL-TIME PREDICTION
CODAR
hourly surface currents
LONGER TERM
SHORT TERM
met. forecast
oceanogr. databases
analysis of currents
hourly motion updates
prediction of currents
actual currents
hour-by-hour monitoring
spill motion prediction
prediction to several hours or several days

Figure 9 Conceptual design for a real-time oil spill motion prediction system utilizing remote sensed surface currents.

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A Portable Geographic Information System (GIS) for Spill Response Planning and Response

by

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The *Exxon Valdez* incident made clear the need for integrated information management and mapping. The importance of tracking spill-related data by shoreline length cannot be over-emphasized. Many programs contain "slick" graphic interfaces but are less than useful for application to large spills. Another key criteria for an operating GIS in this field is that it utilize non-proprietary, standard, and commonly used software thereby enabling updates and growth without relying on a single vendor. This report highlights an available GIS that fulfills these requirements and has undergone critical testing during two major oil spill events.

Because of advances in computer technology, the system can be transported on portable 386 systems for immediate use where ever a spill occurs. Maps of probable spill sites can be stored separately and downloaded into the system on an as needed basis to provide the response staff with the tools to effectively and efficiently complete their duties.

1.0 Background of GIS Development for the PC

GIS, the acronym for Geographic Information System, represents a computer-based method of storing and retrieving map-based information having specific characteristics. A complete definition prepared by the National Science Foundation is presented below:

> "GIS is a system of computer hardware, software and procedures designed to support the capture, management, manipulation, analysis, modeling, and display of spatially referenced data."

The use of Geographic Information Systems received much attention during the last decade, particularly with the development of LANDSAT and SPOT satellite-derived images for use in mapping surface and subsurface features. However, the use of this information was commonly far beyond the capabilities of most planners dealing with a particular problem needing a relatively fast solution. Corporate use of these systems was (and remains) limited to fairly large corporations or specialized firms with specific departments dedicated to the manipulation of spectral data.

At the same time, other GIS firms specialized in large-scale planning (road networks, electrical utilities, etc.) in addition to natural resource mapping. Two of the largest firms in the GIS world, Integraph and Arc/Info are typical in this class. Each system is run on a major computer platform (VAX, SUN, or IBM mainframe) and has its own unique way of handling spatial (map-based) and database information. As before, a GIS department is necessary to maintain the critical mass of training, hardware, and software to successfully complete projects.

With the introduction of the IBM-based Personal Computer, the GIS software industry has exploded. GIS World Magazine, devoted entirely to this specific market, now lists nearly 100 products on the market, clearly dominated by the IBM-based platforms.

As GIS software has blossomed, system costs have dropped radically and the ability to utilize the system after relatively little training has increased significantly. Finally, GIS technology has escaped from behind the often-times closed doors of the GIS shop into the hands of the person who most understands the information desired. The future of GIS can only be more positive as more application-specific software is written and computer processing becomes faster and cheaper.

1.1 Prior Applications for Spill Planning and Response

While GIS applications have been used for many years, particularly in the natural resource fields, few GIS's have received support for spill planning, and no true GIS's were previously used in spill response. A notable exception is a SPANS-based model developed for the Gulf of Mexico to assist spill-making decisions (Trudel et al., 1988). This model is raster-based, meaning it keeps track of information on a pixel-by-pixel basis, which is very good for such activities as tracking the occurrence of different species, but is relatively poor for handling line elements such as shoreline cleanup or impacts.

The use of GIS's in planning, however, is becoming more widespread. A PC-based system has been developed for Alyeska in Prince William Sound using R:base as a database and a modification of an interlinking software package (Anderson et al, 1991) and Harper et al (this issue) discuss one created for an area of British Columbia.

On the MacIntosh side, NOAA and the US Coast Guard make extensive use of HyperCard which, while not a fully functional GIS, provides a rapid means of accessing data tied to a geographic entity. HyperCard was also used extensively on the *Exxon Valdez* spill, particularly to catalogue shoreline cleanup (Haas, 1991).

2.0 Geo/SQL, a New System

For the last two years, we have been very active in development of specific routines and processes that operate within an available GIS package and make it specifically applicable to spill planning and especially spill response. In the following sections, we describe the Geo/SQL system and its capabilities.

2.1 System Description

This system is available for DOS and for SUN SPARC station UNIX. While many GIS's are relatively closed to modification, Geo/SQL intentionally remains extremely open, providing only the basic structure for a GIS application.

Database Information - Information about a map element is stored in either Oracle or R:base, thereby utilizing the SQL (Standard Query Language) format to which many other databases are slowly shifting. Additional support is provided for dBase III and IV. All spatial information is stored in a proprietary database that forms the basis of the software.

The use of Oracle is particularly important because of corporate acceptance. It is one of the most powerful relational databases on the market and can be transported across almost every computer system made.

Graphical Interface - AutoCad serves as the graphic engine (picture formal) of this GIS. The ability of the GIS to utilize AutoCad is considered a great advantage since AutoCad is currently the most ubiquitous Cad software on the market (>60 percent of all Cad systems) and has extensive transfer capabilities between drawing systems. All major government digital map files are now available in AutoCad-compatible formats.

Data exchange capability - There is very good data exchange capability between AutoCad, ArcInfo, Integraph, MacIntosh, and numerous other formats. Currently, AutoCad DXF (data exchange format) is the most widely used with numerous translators on the market today. For instance, a recent AutoCad user's magazine lists over 20 transfer programs between AutoCad and other digital file structures.

Linked Attributes - Geo/SQL software is able to link the following map data sets:

- **Points**: wildlife colonies, and other site-specific pipeline features,
- **Lines**: shoreline elements, and other line-based information,
- **Polygons**: landuse, shrimp distribution, soil type, etc.

Information can be tied to each of the above via four methods:

- **Simple**: direct one feature, one attribute,
- **Linked**: one feature linked to several attributes residing in different tables,
- **Point GeoCoding**: a record is tied to a site feature at a specific distance (a bird colony = 12 m from start of a shoreline segment), and
- **Line GeoCoding**: references segment lengths to distance (heavy oil extends from 125-2812 m along a shoreline segment).

User Friendliness - As part of the total decentralized approach, Geo/SQL with specific routines related to spill response and planning offers a series of pulldown menus to provide answers to repetitive queries. This ability to pre-define and simplify common or repetitive queries is clearly advantageous.

Interconnectivity - In the forthcoming era of hardware interconnectivity, it is important that the GIS not be tied to a proprietary system that supports a limited list of plotters, printers, and monitors. AutoCad is exceptional in supporting most of the common hardware devices. Many other systems are not as adaptable.

Speed of Performance - Getting an answer rapidly is imperative. The Geo/SQL system efficiently accesses the data and generates a map within a reasonable amount of time. Of course, performance can be upgraded by utilizing a more expensive platform, e.g. a Sun workstation, but we have focussed on PC to maintain portability necessary for spill response.

Cost of the System - The cost of this system is highly competitive with others of similar capability. When planning a GIS, system costing should include new hardware purchases, software purchases, maintenance and support, training and operational personnel. The presence of AutoCad, R:base, or Oracle substantially reduces the upfront costs of operating this system. However, it must be remembered before entering the GIS world, that the equipment and software form a lesser portion of the total expense. Data collection, analysis, and digitization always is more costly than system costs.

2.1.2 System Capabilities

Geo/SQL is able to produce on-demand maps at any scale and selectively overlay both graphical and text information at the option of the operator. A brief summary of the types and sources of overlay data are discussed below.

Data Set 1. Latitude and Longitude

Most oceanographic and logistical data are in a Lat/Long format. However, in order to maintain a metric basis (where 1 meter in the x axis = 1 meter in the y axis) most government agencies and corporate facilities managers use State Plane or UTM (Universal Transverse Mercator) Coordinates. We provide routines to convert one to the other.

Data Set 2. Topographic Features

This category includes a wide variety of information commonly seen on topographic maps, including such features as shorelines, rivers, lakes, topography, and bathymetry. There exist several sources of digital information for these features. The government as well as several private vendors sell it relatively cheap (e.g. $250/quad sheet). We have used this digital data for several projects and found it extremely useful, especially for providing a uniform, government-based reference for topographic features, particularly the outline of the shoreline, rivers, and lakes, as well as road networks and airports. The primary format is DXF AutoCad in UTM coordinates.

Data Set 3. Facilities and Infrastructure

This information is available from company records or must be digitized into the system. We have linked such information as marinas, equipment depots, tanks and tank farms, and pipelines into our system.

When obtaining information from other sources, the importance of format interchange becomes critical. Our initial review of major oil company systems reveals that a variety of mapping and Cad systems are being used, particularly AutoCad, Intergraph, and ARC/INFO. AutoCad offers a viable means to exchange this information without having to revert to special, one-of-a-kind programs.

Data Set 4. Cultural Resources

The location of many cultural resources has become extremely important as a result of the *Exxon Valdez* spill. It is unlikely that any major spill will be cleaned without first assurances that the designated area is free of archeological resources. These sites can be entered into the system as point objects.

Data Set 5. Shoreline Sensitivity

This is one of the most important functions of a spill response database and is an inherent part of all sensitivity maps. Geo/SQL provides direct linkages from any section of shoreline to the database. We have used Geo/SQL to track shoretype and oceanographic data for over 23,000 km of shoreline in Alaska. Shoreline characteristics catalogued include shoretype, length, azimuth, backshore/foreshore slope, fetch, and latitude/longitude and UTM coordinates (Gundlach and McMahon, 1991)

Data Set 6. Wildlife Habitat Information

Knowledge of primary wildlife resources such as rookeries, nesting areas, commercial clam beds, etc. is of primary importance in both planning and response efforts. Previously this has been a primary feature of all sensitivity maps. Data stored as point objects or polygons to reflect the location and range of the species in question.

Data Set 7. Logistics Data

Site characteristics (port facilities, runway sizes) are likely to be of importance during a major spill response, especially in remote areas.

Data Set 8. Typical Sea Ice Coverage

The location of sea ice is available from published reference material. The location of the most common ice front by month has been entered for much of Alaska with reference to distance from the shoreline and season.

Data Set 9. Shoreline Pollution Levels after a Spill

The *Exxon Valdez* incident amplified the need for this GIS capability. The GIS developed by the proposed team for the State of Alaska tracked this information from the second day of the spill through 1990. It is a critical GIS ability is to indicate the change over time for each segment of shoreline. Several other GIS have difficulties in differentiating oil levels for a single part of the shoreline when it is tied to concentrations extending along a longer section.

In addition to oil levels, we are able to track such spill-related aspects as cleanup history, State and Federal signoffs, degree of exposure, etc.

Data Set 10. Response Equipment and Personnel Deployment Data

We have used the GIS to access and update the location of any spill equipment and storage depots. During the response, the location of personnel can be tied to a shoreline or offshore location. Major pieces of response equipment can also be tied to a zone or specific site, depending on the degree of tracking desired.

Data Set 11. Spill Trajectory Model Output

Several oil spill trajectory models are currently available. The AutoCad Dxf format offers the capability of entering input data and graphically presenting the results. AutoCad has particularly easy data entry capabilities. The new version 11 of AutoCad has C-binding which offers the ability of running the computer model directly from the AutoCad screen.

3.0 Response to the *Exxon Valdez*

The Geo/SQL system was (and currently remains) the primary GIS used by the State of Alaska to track all elements of the spill. It has been successfully operating since the third day of the spill to provide information to the State Coordinator, his staff, and the public. In addition, regular exchanges of information are made with other State agencies, Exxon, and federal response agencies.

Specifical information catalogued includes:

1. Oil distribution derived from field overflights,
2. Shoreline impacts derived from overflight and ground surveys,
3. Station data: physical, biological, and chemical;
4. Profile data: topography, oil thickness, penetration, and coverage;

5. Cleanup data: oil characteristics, cleanup type, and inspection records;
6. Photographic (video and still) data;
7. Shoretype data in terms of sensitivity ranking; and
8. Biological features (haulout areas and rookeries, etc.).

A series of selected access procedures were developed to protect important data and restrict users from entry into non-pertinent aspects of the program.

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SPILL RESPONSE MANUALS FOR THE COASTS OF BRITISH COLUMBIA

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ABSTRACT

Two manuals have been prepared for the coasts of British Columbia that provide guidelines for (1) the assessment and (2) the protection and cleanup of oiled shorelines. The Shoreline Cleanup Advisory Team (SCAT) Manual is intended to provide guidelines for establishing a shoreline assessment program to characterize, document and monitor the oil conditions, geomorphology, ecology and cultural resources of the shorelines affected by a spill. The SCAT process provides the documentation through a variety of surveys including aerial reconnaissance, aerial videotape, ground surveys and long-term monitoring programs. The survey teams work ahead of the cleanup teams to collect data necessary for planning and implementation of cleanup operations. The teams also develop a set of response options onsite which are then submitted to the regulatory agencies and Cleanup Operations management for review and comment. Once the most appropriate response option is identified, a response plan is prepared and submitted to Cleanup Operations for implementation. The BC Shoreline Protection and Cleanup Manual describes state-of-the-art spill response techniques for the protection and cleanup of the coastal environments of British Columbia. Techniques that are considered experimental or that would not normally apply to the BC shorelines have not been included. Similarly, the use of chemical dispersants and sinking or gelling agents are not included as approval for their use is given only on a case-by-case basis.

INTRODUCTION

Environment Canada and BC Environment recently have contracted a number of studies related to oil spill response in British Columbia. Two of the completed projects, that deal with oiled shorelines, are closely related (Figure 1) and are outlined in this discussion.

Environment Canada funded the preparation of a "Shoreline Cleanup Advisory Team (SCAT) Manual" for British Columbia. This project was developed because of the recognized need to improve large-spill shoreline cleanup response. The SCAT method was adopted due to its successful application on the "Nestucca" and "Exxon Valdez" responses and to its proven usefulness as a planning and operations tool. BC was chosen as the prototype for this Environment Canada manual because of its diverse and productive coastal environment. This coastal environment also closely resembles that of Alaska, which has been the most extensive previous application of the process (Owens and Teal, 1990; Teal, 1991). This manual is intended to serve as a model for other coastal areas in Canada.

The Environmental Emergency Services Branch of BC Ministry of Environment initiated the development of a "Shoreline Protection and Cleanup Manual" as part of a programme to improve the Ministry's capability to respond to a marine oil spill event. The primary function of the Manual is to provide the three Ministry Oil Spill Response Teams with a reference document and field guide that promotes effective and rapid shoreline protection and cleanup decisions during a spill event, as well as improving the teams knowledge and recognition of the different shoreline types along the British Columbia coast. The technical content in the manual related to logistics and countermeasure decision-making also will be used to upgrade existing response team members' skills and to train new members

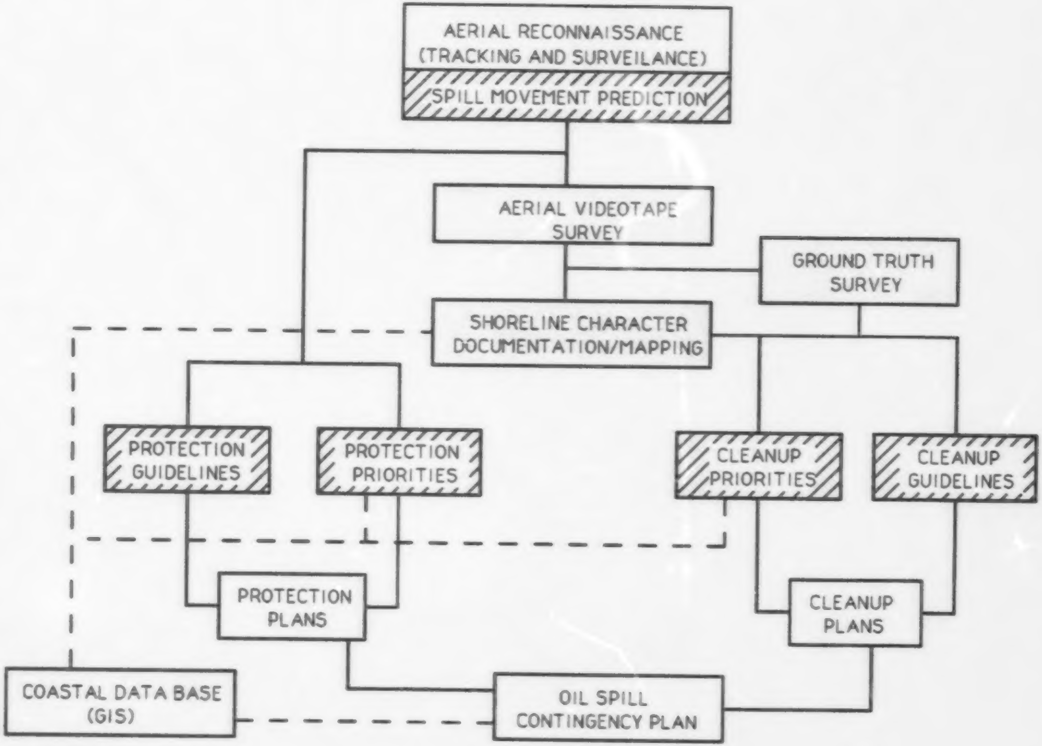

AERIAL RECONNAISSANCE
(TRACKING AND SURVEILANCE)
SPILL MOVEMENT PREDICTION
AERIAL VIDEOTAPE SURVEY
GROUND TRUTH SURVEY
SHORELINE CHARACTER DOCUMENTATION/MAPPING
PROTECTION GUIDELINES
PROTECTION PRIORITIES
CLEANUP PRIORITIES
CLEANUP GUIDELINES
PROTECTION PLANS
CLEANUP PLANS
COASTAL DATA BASE (GIS)
OIL SPILL CONTINGENCY PLAN

Figure 1. Schematic Relationship Between SCAT Manual (light shading) and Protection and Cleanup Manual (line shading).

of these response teams. In addition, the logic developed for various countermeasure decision options in the manual are to be adapted and incorporated into an Oil Spill Response Information System, currently being developed by the Environmental Emergency Services Branch, for identifying pre-spill protection and cleanup countermeasure options for sensitive shoreline segments based on inventory data and modifying these options during a spill event based on real time data.

SCAT MANUAL

Concerns with shoreline cleanup response have existed for some time, but generally have received little notice. However, recent spill events and public inquiries and reviews have brought more attention to bear on this topic. One of the more significant problems following an oil spill usually is the lack of appropriate information and/or its proper use during response planning and decision making. The SCAT process was seen as a partial solution to this problem. The method involves systematic and comprehensive procedures that provide a real-time assessment of shoreline oil conditions. This data base can then be used to advise cleanup operations personnel in scoping and planning response actions.

The Shoreline Cleanup Advisory Team (SCAT) provides detailed assessments of stranded oil, geomorphologic features, and environmental resource, human use, and cultural sensitivities along affected shorelines using standardized procedures, terminology, and definitions. It is primarily applicable to larger spills from tankers, coastal freighters, well blowouts, marine terminals, etc. where more than a few kilometers of shoreline have been oiled or are threatened by an oil spill.

The SCAT process described in this manual is based primarily on experience gained following the 1989 "Exxon Valdez" and "Nestucca" spills. Although modified for use along the British Columbia coast, this concept can be applied in a generic manner to most coastal environments worldwide.

This document is not intended to be used as a definitive protocol for shoreline assessment, but rather as the foundation from which to build or fine tune the actual procedure that would be followed in the event of a spill. In practice, the SCAT process can be quickly reconfigured, expanded or selectively applied to accommodate the idiosyncrasies of a given spill or its organizational structure. The SCAT process described in this manual reflects the opinion of Woodward-Clyde and Environment Canada with respect to a typical well-rounded, practical version likely suitable for most spill situations.

Overall, the SCAT process is implemented through the Shoreline Cleanup Advisory Team (SCAT), a management structure which is supported by one or more Shoreline Assessment Teams (SATs) and typically by several scientific/technical coordinators or advisors. The SATs may be specialized according to the type of survey they conduct (reconnaissance, video, assessment, or monitoring). Likewise the coordinators/advisors may be specialized according to discipline (e.g., archaeology, ecology, logistical support). An example of a typical SCAT organizational chart is provided in Figure 2.

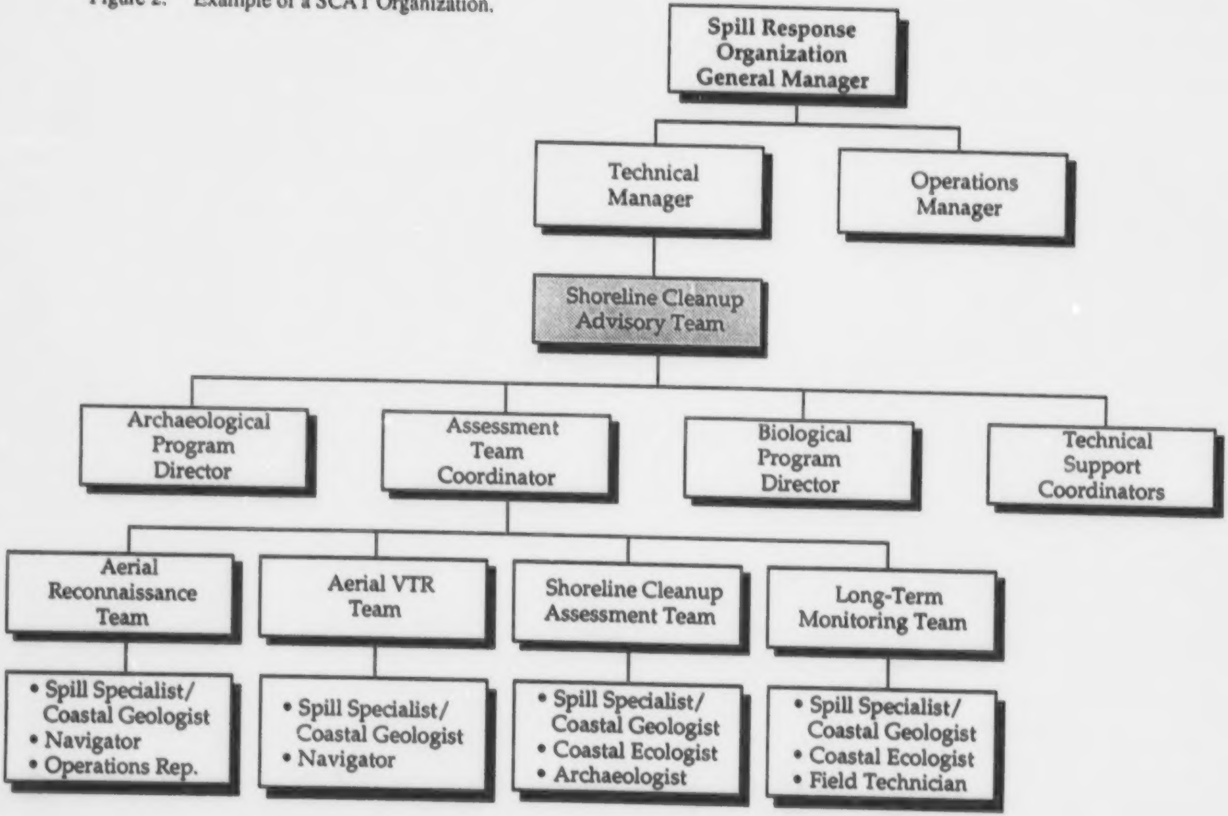
The SCAT process typically is established by the spiller or lead government agency taking responsibility for the spill response. The SATs ideally would be staffed by impartial experts from consulting firms, academia, or industry but may also be staffed by government agency personnel with expertise in spill response, coastal geology, or intertidal ecology and archaeology.

It is effective for the SCAT team to be responsible for:

- Shoreline assessment surveys
- Shoreline sensitivity identification
- Technical advice for shoreline cleanup activities
- Regulatory approval for shoreline cleanup
- Shoreline monitoring program

The shoreline assessment surveys, including the monitoring program, are one of the most important functions of the SCAT and are the focus of this manual. Shoreline sensitivity identification, such as ecological, human use and cultural concerns, are provided by using available databases and compilations. These exist to various degrees of detail for different coastal areas. These data bases are supplemented with current, real-time or new data at the time of a spill. Technical advice and regulatory approval for shoreline cleanup is provided by the SCAT mainly through recommendations from the field SATs but also by negotiations with the appropriate regulatory agencies. In general, the recommended response options for a given segment or area are submitted by the SATs to the SCAT Technical Manager who then reviews them, along with Operations, taking into account the environmental, human use, and cultural sensitivities and other shoreline characterization data, as well as available response resources and technique effectiveness. The SCAT Manager then presents the most effective and environmentally sound response option to the agencies for their review and approval. Once a mutually acceptable response option is identified and approved, the SCAT Manager then forwards the plan to the Cleanup Operations Manager for implementation. A diagram of this process is provided in Figure 3. In some situations, however, the SATs may have the authority to determine the most

Figure 2. Example of a SCAT Organization.


Spill Response Organization General Manager
Technical Manager
Operations Manager
Shoreline Cleanup Advisory Team
Archaeological Program Director
Assessment Team Coordinator
Biological Program Director
Technical Support Coordinators
Aerial Reconnaissance Team
Aerial VTR Team
Shoreline Cleanup Assessment Team
Long-Term Monitoring Team
• Spill Specialist/ Coastal Geologist
• Navigator
• Operations Rep.
• Spill Specialist/ Coastal Geologist
• Navigator
• Spill Specialist/ Coastal Geologist
• Coastal Ecologist
• Archaeologist
• Spill Specialist/ Coastal Geologist
• Coastal Ecologist
• Field Technician

appropriate response option, including natural recovery, in the field, particularly if the team is staffed by agency and native council representatives. Thus, making decisions and obtaining approvals on the response option may range from a mechanism required to pass through different levels of management and committees, to one which is integrated into the ground assessment survey team. In either case, decisions and approvals would include the same personal and thought processes and would draw heavily on the shoreline survey information.

The shoreline surveys are the primary data collection component of the SCAT process. Generally, they are performed in four successive phases:

- Aerial reconnaissance survey
- Aerial videotape survey
- Ground assessment survey
- Long-term monitoring survey

The SAT aerial reconnaissance surveys provide an overall perspective of the magnitude of the spill as well as identifying shorelines that are threatened or currently impacted by oil. This information is used to establish shoreline protection locations and their priorities and to direct the initial SAT aerial videotape surveys to the most heavily impacted shorelines. Documentation provided by the aerial videotape surveys is then utilized by Operations for cleanup planning and scoping purposes and by the SCAT for establishing priorities for the SAT ground surveys. The ground surveys are the most detailed and comprehensive of the three assessment phases and provide the SCAT with the necessary data to formulate appropriate response recommendations in addition to furnishing Operations with the required information for implementing the response program and minimizing impacts to the environmental and cultural resources of the area. Once the more heavily impacted shorelines have been surveyed, a long-term monitoring

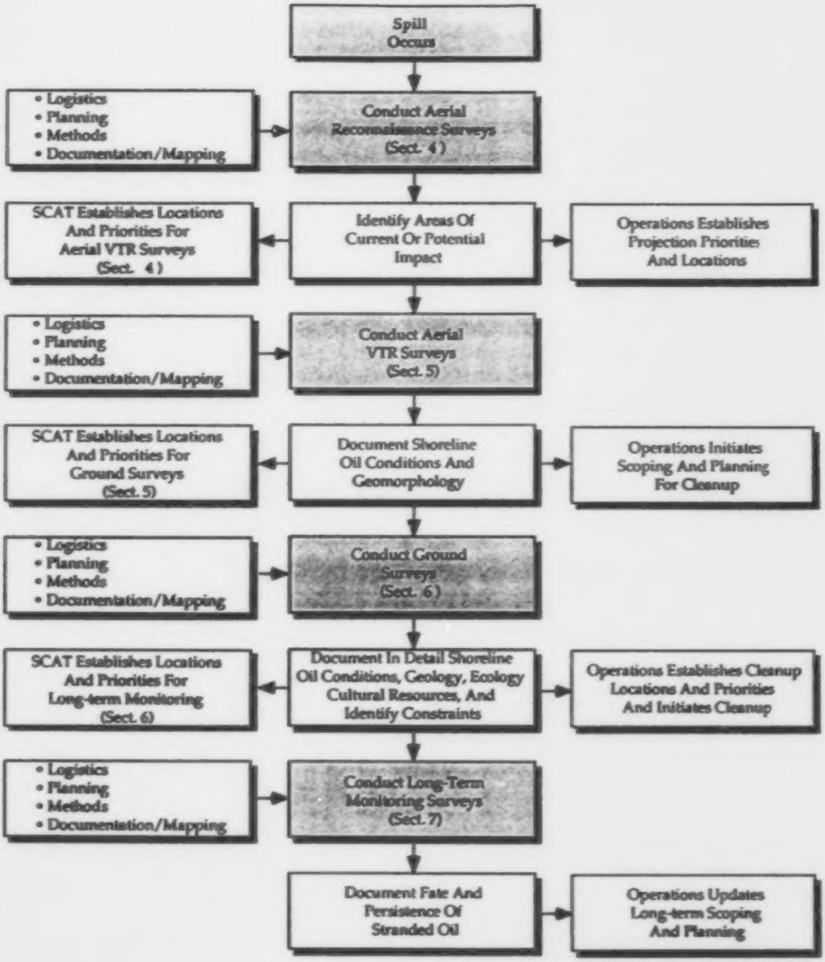

Spill Occurs
• Logistics
• Planning
• Methods
• Documentation/Mapping
Conduct Aerial Reconnaissance Surveys (Sect. 4)
SCAT Establishes Locations And Priorities For Aerial VTR Surveys (Sect. 4)
Identify Areas Of Current Or Potential Impact
Operations Establishes Projection Priorities And Locations
• Logistics
• Planning
• Methods
• Documentation/Mapping
Conduct Aerial VTR Surveys (Sect. 5)
SCAT Establishes Locations And Priorities For Ground Surveys (Sect. 5)
Document Shoreline Oil Conditions And Geomorphology
Operations Initiates Scoping And Planning For Cleanup
• Logistics
• Planning
• Methods
• Documentation/Mapping
Conduct Ground Surveys (Sect. 6)
SCAT Establishes Locations And Priorities For Long-term Monitoring (Sect. 6)
Document In Detail Shoreline Oil Conditions, Geology, Ecology Cultural Resources, And Identify Constraints
Operations Establishes Cleanup Locations And Priorities And Initiates Cleanup
• Logistics
• Planning
• Methods
• Documentation/Mapping
Conduct Long-Term Monitoring Surveys (Sect. 7)
Document Fate And Persistence Of Stranded Oil
Operations Updates Long-term Scoping And Planning

Figure 3. Implementation Sequence for the SCAT Process.

program can be implemented to assess the fate and persistence of stranded oil and recovery of affected shorelines. This program provides for a feedback mechanism to evaluate the effectiveness and effects of earlier cleanup decisions and response options. The less heavily impacted shorelines will continue to be surveyed until the entire affected area has been delineated and documented.

OVERVIEW OF THE SHORELINE ASSESSMENT SURVEY

The first step of the SCAT process is to conduct an aerial reconnaissance survey to describe the general oil conditions and to define the limits of the region to be studied in subsequent, and more detailed, aerial and ground surveys. The reconnaissance surveys are typically conducted by an oil spill specialist, navigator, and Operations representative (Figure 2). The reconnaissance is followed by an aerial videotape recording (VTR) survey (Owens and Reimer, 1991), conducted by a coastal geologist or oil spill specialist/videotape camera person and a navigator. The VTR survey provides low-altitude documentation of the shoreline from which preliminary shoreline character and initial oil distribution maps are produced. The final, and most comprehensive stage is the ground survey. The ground survey is carried out by a team that consists primarily of a coastal geologist with oil spill experience and a coastal ecologist. An archaeologist is required for areas that are known or suspected to contain cultural resources. Other team members such as Operations, government agency, and land owner/manager personnel can provide valuable input and assistance but are not essential to the completion of the surveys.

Initially, the shoreline is divided into predetermined alongshore segments within which the shoreline character is relatively homogenous in terms of physical features and sediment type. Longer segments may be divided into subsegments should oil conditions vary significantly from one portion of the segment to the other. The field team, using appropriate vehicle, boat, or aircraft support, then conducts systematic surveys of the individual segments to define shore-zone features, describe the ecological community, identify human uses and cultural resources, and document the character and distribution of any stranded oil. In addition, the team evaluates apparent or potential effects of the oil or proposed cleanup activities on the human uses and ecological and cultural resources.

Each segment is photographed and/or videotaped and is described using predefined methods and terminology to ensure uniformity of information between sections of shoreline and between survey terms, if more than one team is deployed. The data sheets and forms used for documentation are included in the manual and are designed so that the more pertinent information can be input, using templates, to a database for storage and analysis.

Information generated by aerial and ground surveys is then used on a site-specific basis to evaluate; 1) whether or not a section of shoreline warrants cleanup, 2) the priority for cleanup response, and 3) the most appropriate response options to control or remove the oil. The field survey data are combined with other information on human uses, ecological resources, or cultural features to evaluate any timing or operational constraints that may modify the recommended response activities. This evaluation is subsequently used by planners and Operations personnel to develop a response program.

The long-term monitoring surveys or program consists of establishing several transects across the beach at representative locations and conducting periodic surveys to calculate oil cover, elevations, sediment distribution, biota types and densities, oil penetration, and other parameters along each transect. Observations of oil character and classification can also be made. The program is very useful in documenting the effectiveness and effects of various cleanup techniques and natural cleansing processes in addition to evaluating local coastal processes (Owens, 1991). Sites should be set up in areas with different degrees of oil conditions, exposures, treatment techniques (including no treatment), substrates, biological impacts, etc. to monitor the changes in oil conditions and recovery over time. This program proved essential in the documentation of both induced and natural cleansing of the shorelines following the "Exxon Valdez" incident. The monitoring surveys are conducted by teams consisting of an oil spill specialist/coastal geologist, coastal ecologist and a field technician.

OBJECTIVE OF THE SHORELINE ASSESSMENT SURVEYS

The objectives of the four components of the shoreline surveys are:

Aerial Reconnaissance/Protection Surveys

- To gain an overall perspective on the magnitude of the spill
- To locate oiled and threatened shorelines
- To provide input to Operations and to the Shoreline Cleanup Advisory Team for determining locations and priorities for protection actions and aerial videotape surveys

Aerial Videotape Recording (VTR) Surveys

- To document, in a detailed and consistent manner, the shoreline oil conditions throughout the spill area in video and graphic (map) formats
- To document the locations and degree of shoreline oil conditions so that long term cleanup planning and prioritization can be initiated

- To provide information to the Shoreline Cleanup Advisory Team for establishing locations and priorities for ground surveys
- To enable mapping of other spill-related data such as anadromous stream and ecological habitat locations, human uses, potential logistical staging areas, shoreline accessibility, potential cultural resource site locations, etc.

Ground Surveys

- To collect information on shoreline oil conditions and on the physical and ecological character of the oiled shoreline so that appropriate cleanup response operations can be developed
- To identify and describe any environmental, human use, or cultural features that might affect, or be affected by, the timing and implementation of response activities
- To organize the data and shoreline documentation so that it can be easily stored, retrieved and analyzed

Long-Term Monitoring Surveys

- To document changes over time in shoreline oil conditions (fate, character, distribution) and shoreline integrity, which have been caused by the efforts of the cleanup operation and/or natural processes
- To document changes/recovery of biota over time, in impacted areas which have been cleaned and/or left to natural recovery
- To evaluate the effectiveness and effect of the cleanup decisions and options which were applied to various shoreline segments

APPLICATION OF SCAT PROCESS

The SCAT process is designed to provide several essential functions including; l) serving in a technical advisory capacity to Operations to assist them in the spill response decision making, planning and implementation, 2) providing a mechanism for regulatory and land owner/manager input into the documentation and response option recommendation process, and 3) generating a database to assist cleanup operation planning, implementation and progress tracking.

The technical advice is provided primarily in the form of data on shoreline oil conditions, geomorphology, accessibility and ecological, cultural, and human use constraints. This data is obtained from the aerial reconnaissance, low-altitude videotape, and/or ground surveys and converted into a simplified form for use by Operations in response planning and implementation. The aerial videotapes documentation forms, sketch maps, and response option recommendations generated by the field teams and synthesized by the SCAT managers and staff are very useful in identifying the appropriate cleanup technique(s) and the operational and logistical requirements for implementing the response program. For example, the videotapes can be reviewed to determine the nature of the shoreline, vehicle, vessel, and helicopter accessibility, exposure, and general oil condition. The forms and sketch maps further define the location, degree, and character of the oil and identify any of the constraints that must be taken into account. The response recommendations are reviewed by SCAT personnel in terms of available logistics, implementation time, effectiveness on similar shorelines, etc. to determine the most appropriate and effective response option which is then submitted to Operations. This information greatly reduces the potential for unforeseen problems once the cleanup crews reach the shoreline and increases the overall efficiency of the operation. In general, the SCAT allows Operations to focus on shoreline protection and cleanup rather than on collecting the data and obtaining the necessary approvals.

Regulatory input for incidents where the spiller takes responsibility for the response is facilitated by the SCAT in two ways. The first is through participation on the ground survey teams where they can provide input into the documentation of the oil conditions and the response option recommendations. The second is through the review process where copies of the SAT survey reports, along with the final response recommendations from the SCAT and Operations, are submitted to the regulatory agencies for their review and comment. Once agreement is reached on the appropriate course of action, the response plan, including cleanup techniques and constraints, is resubmitted to Operations for implementation. The field data is entered into a database and geographical information system (GIS) to allow the generation of statistics and maps displaying a variety of information such as oil distribution, segment locations, shoreline sensitivities, number of kilometers surveyed, number of kilometers treated, cleanup activities by segment, sediment or shore type distribution, exposure levels, and numerous others. This type of information has proven vital in planning, implementing and tracking a large spill response operation.

BC SHORELINE PROTECTION AND CLEANUP MANUAL

In the event of an oil spill along the coast of British Columbia, it is likely that a portion of the coastline will become oiled. The potential adverse effects of a coastal oil spill can be significantly reduced if proper protection and cleanup actions are taken promptly. The purpose of the manual is to provide the On-Scene Coordinator (OSC) and his or her staff with a systematic, easy-to-apply methodology that can be used to assess the threat of an oil spill and to select the most appropriate shoreline protection and cleanup techniques. This manual describes state-of-the-art spill response techniques for the protection and cleanup of the coastal shorelines of British Columbia. Techniques that are considered experimental or that would not normally apply to the BC shorelines have not been included. Similarly, the use of chemical dispersants and sinking and gelling agents also are not included as approval for use is given only on a case-by-case basis. A discussion of waste handling and temporary disposal is provided.

The manual is structured to provide decision-making guidelines for determining, in a given situation, which protection and cleanup techniques would be most effective for a specific shoreline type. A detailed discussion of the factors involved in the decision-making process is provided and includes oil characteristics and behavior, shoreline classifications, protection and cleanup priorities and implementation requirements, and impacts associated with the cleanup operations.

The manual format is designed to follow the sequence of events that would be expected to occur in a spill response (Figure 4), assuming the spill originated offshore. Specifically, the initial response task will be to assess the size of the spill and estimate the location(s) and time(s) of shoreline contact. The general information needed to conduct this task is provided in Section 2.0 (Spill Characteristics and Behavior). Information on the assessment of the degree of shoreline oil conditions is also included in Section 2.0. This phase of the sequence is, in essence, the first stage of the SCAT process.

After the nature and direction of the oil spill have been estimated, the next task is to determine the type(s) of shoreline that could be impacted and the potential persistence of the oil. Section 3.0 (Shoreline Classification) provides information on the common shoreline types found along the BC coast and the potential persistence or residence time of various oil types. Additional information on the common shoreline types and coastal processes is provided in Appendix D (Characterization of BC Coastline).

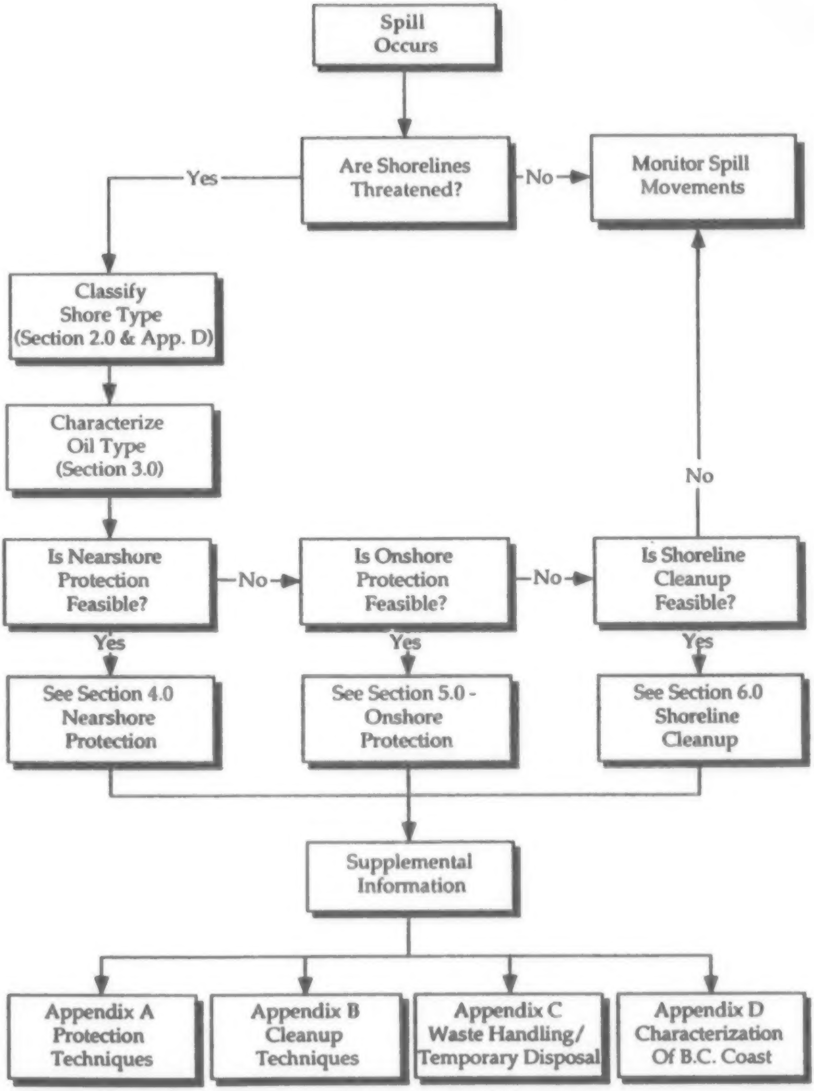

Spill Occurs
Are Shorelines Threatened?
Yes
No
Monitor Spill Movements
Classify Shore Type (Section 2.0 & App. D)
Characterize Oil Type (Section 3.0)
Is Nearshore Protection Feasible?
No
Is Onshore Protection Feasible?
No
Is Shoreline Cleanup Feasible?
No
Yes
Yes
Yes
See Section 4.0 Nearshore Protection
See Section 5.0 - Onshore Protection
See Section 6.0 Shoreline Cleanup
Supplemental Information
Appendix A Protection Techniques
Appendix B Cleanup Techniques
Appendix C Waste Handling/ Temporary Disposal
Appendix D Characterization Of B.C. Coast

Figure 4. BC Shoreline Protection and Cleanup Manual Flow Diagram.

The protection of sensitive shorelines involves an evaluation of the response options that can be implemented in the nearshore zone (Figure 5), followed by onshore protection options (Figure 6) discussed in Sections 4.0 and 5.0. Information and decision guides are provided in Section 4.0 (Nearshore Protection) to establish priorities for areas to be protected, identify applicable techniques for each area, determine logistics and implementation requirements and a brief description of each technique. More detailed descriptions are provided in Appendix A (Protection Techniques).

In the event that nearshore protection is not feasible or is ineffective, Section 5.0 (Onshore Protection) provides information for determining priorities, applicable techniques, logistics, and implementation requirements and a brief description of each technique. Detailed technique descriptions are provided in Appendix A (Protection Techniques). In addition to discussing the available response options, Sections 3.0, 4.0, and 5.0 provide guidelines on establishing priorities, evaluating technique applicability, and implementation.

Once the protection measures are implemented where practicable, the next stage is the cleanup of oil-impacted shorelines. Through a series of decision guides, Section 6.0 (Onshore Cleanup) describes the steps necessary to implement a shoreline cleanup program (Figure 7). In sequential order, these are:

- Cleanup priorities
- Identification of applicable techniques
- Determination of logistical and implementation requirements
- Identification of potential impacts and operational constraints
- Brief descriptions of each technique

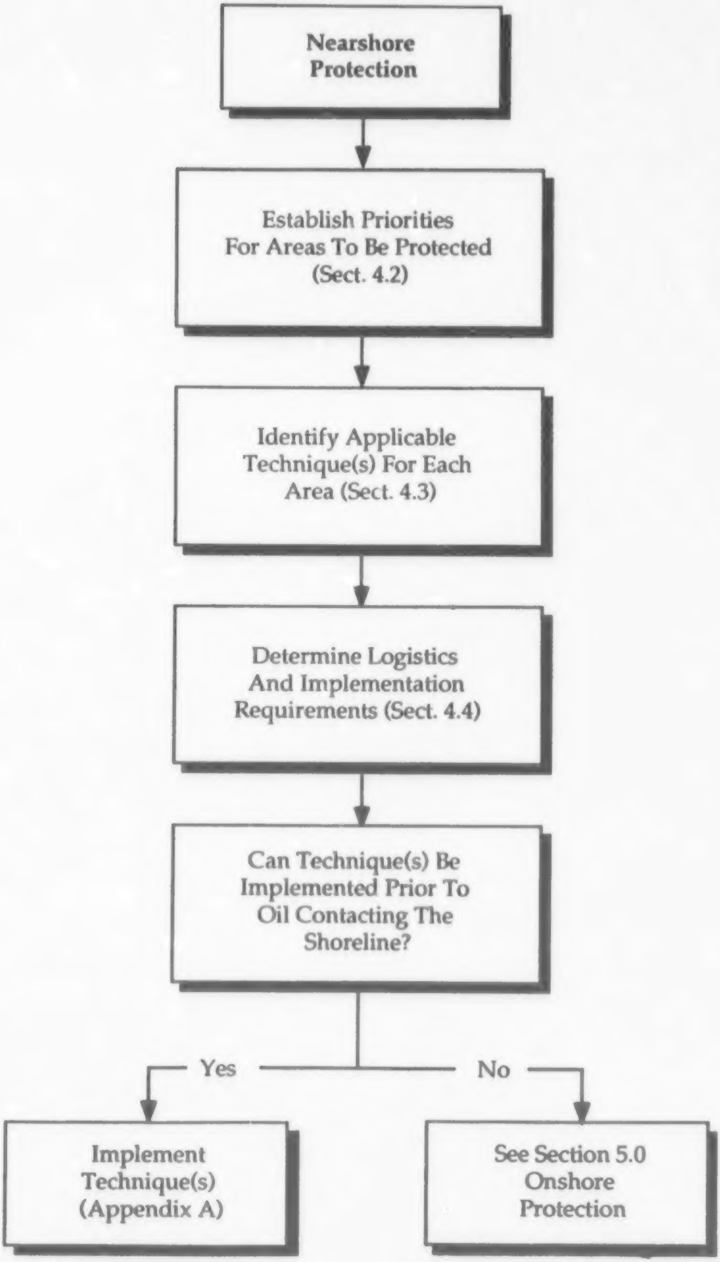

Nearshore Protection
Establish Priorities For Areas To Be Protected (Sect. 4.2)
Identify Applicable Technique(s) For Each Area (Sect. 4.3)
Determine Logistics And Implementation Requirements (Sect. 4.4)
Can Technique(s) Be Implemented Prior To Oil Contacting The Shoreline?
Yes
No
Implement Technique(s) (Appendix A)
See Section 5.0 Onshore Protection

Figure 5. Sequence of Nearshore Protection Activities and Decisions (Section 4).

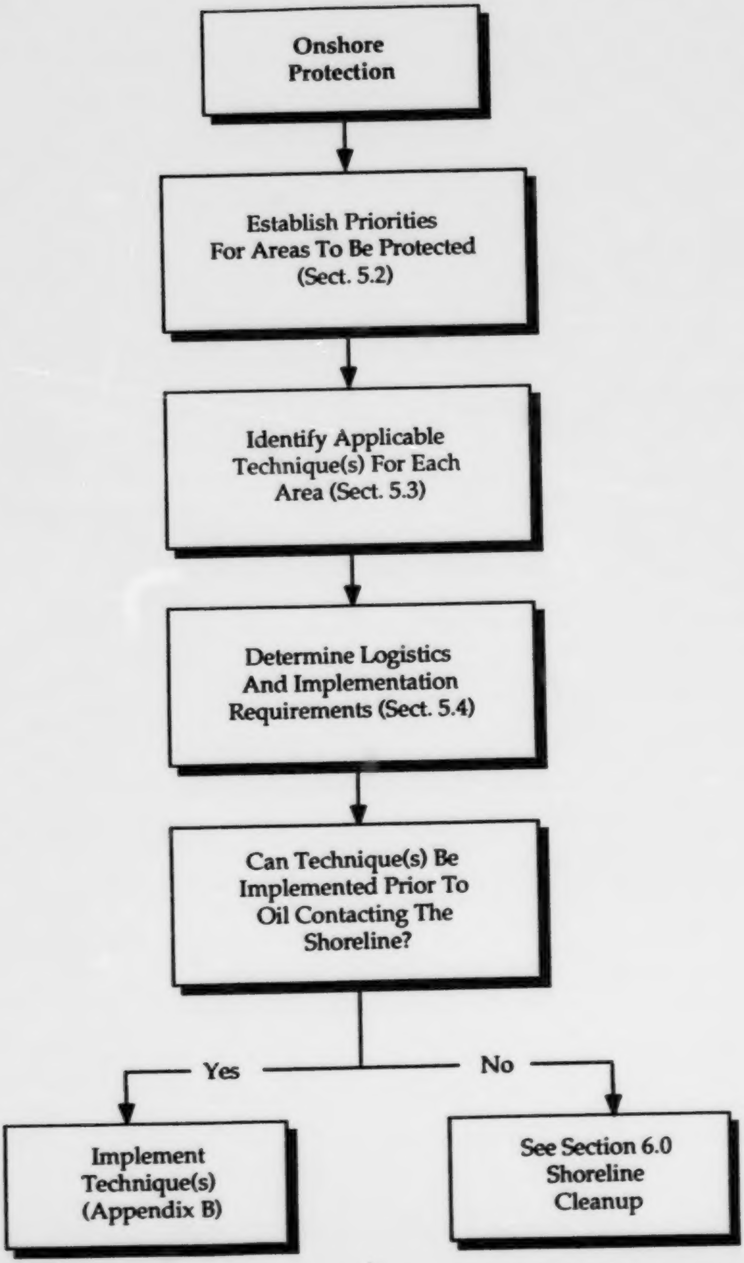

Onshore Protection
Establish Priorities For Areas To Be Protected (Sect. 5.2)
Identify Applicable Technique(s) For Each Area (Sect. 5.3)
Determine Logistics And Implementation Requirements (Sect. 5.4)
Can Technique(s) Be Implemented Prior To Oil Contacting The Shoreline?
Yes
No
Implement Technique(s) (Appendix B)
See Section 6.0 Shoreline Cleanup

Figure 6. Sequence of Onshore Protection Activities and Decisions (Section 5).

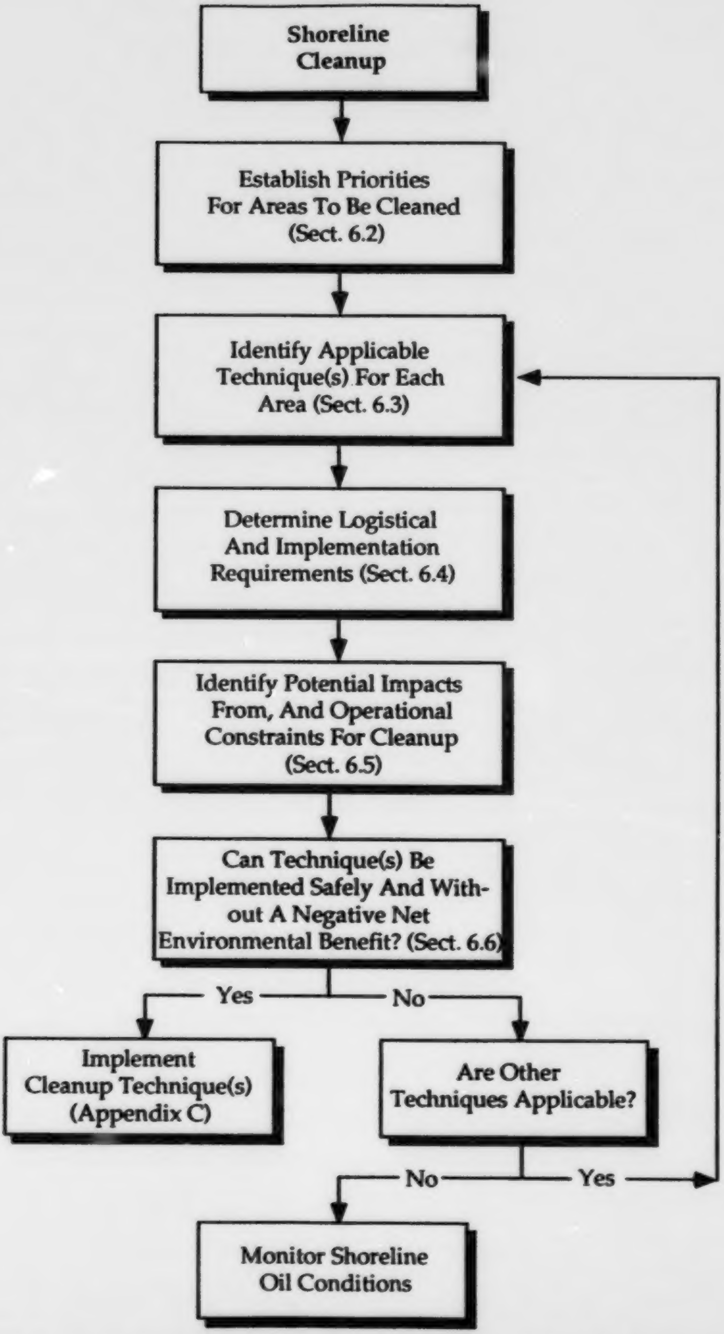

Shoreline Cleanup
Establish Priorities For Areas To Be Cleaned (Sect. 6.2)
Identify Applicable Technique(s) For Each Area (Sect. 6.3)
Determine Logistical And Implementation Requirements (Sect. 6.4)
Identify Potential Impacts From, And Operational Constraints For Cleanup (Sect. 6.5)
Can Technique(s) Be Implemented Safely And Without A Negative Net Environmental Benefit? (Sect. 6.6)
Yes
No
Implement Cleanup Technique(s) (Appendix C)
Are Other Techniques Applicable?
No
Yes
Monitor Shoreline Oil Conditions

Figure 7. Sequence of Shoreline Cleanup Activities and Decisions (Section 6).

More detailed technique descriptions are provided in Appendix B (Cleanup Techniques). Guidelines for the handling and temporary storage of recovered oil and oily debris are provided in Appendix C (Waste Handling and Temporary Storage).

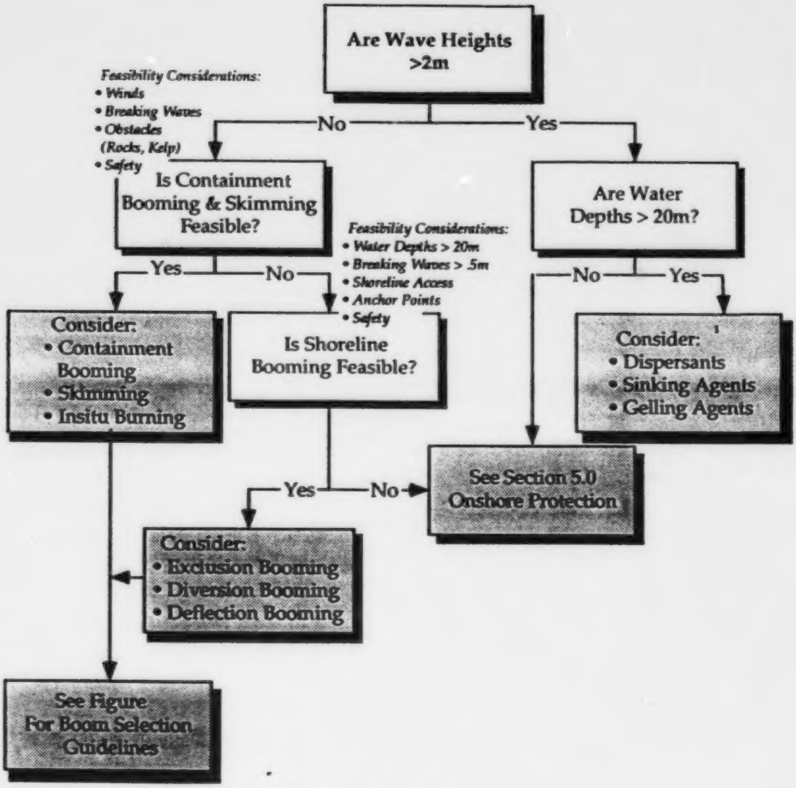
The format of the manual involves an emphasis on decisions guides in the selection of appropriate techniques for the many situations that can occur following a spill. Figures 8 and 9 illustrate this concept with one example each for nearshore protection and onshore protection respectively.

RELATIONSHIP OF THIS MANUAL TO OTHER SPILL PLANNING DOCUMENTS

This Shoreline Protection and Cleanup Manual is one of four oil spill planning documents that have been prepared for the coastal areas of British Columbia. The other three documents are:

- The British Columbia Marine Oil Spill Contingency Plan
- The British Columbia Shoreline Cleanup Advisory Team Manual
  (this paper; described above)
- The British Columbia Physical Shorezone Mapping System
  (Harper, Howes and Reimer; 1991)

The BC Marine Oil Spill Contingency Plan provides information on notification procedures, establishing a spill response organization and procuring spill response resources, equipment and supplies. The Plan is intended to provide a coordinated response by the Province of British Columbia, in concert with other responding governments, industry or communities, to major oil spills affecting marine and estuarine waters. The plan outlines the organization and duties of the provincial government and identifies notification contacts and procedures. It provides a variety of


Are Wave Heights >2m
Feasibility Considerations:
• Winds
• Breaking Waves
• Obstacles (Rocks, Kelp)
• Safety
No
Yes
Is Containment Booming & Skimming Feasible?
Are Water Depths > 20m?
Feasibility Considerations:
• Water Depths > 20m
• Breaking Waves > .5m
• Shoreline Access
• Anchor Points
• Safety
Yes
No
No
Yes
Consider:
• Containment Booming
• Skimming
• Insitu Burning
Is Shoreline Booming Feasible?
Consider: [1]
• Dispersants
• Sinking Agents
• Gelling Agents
Yes
No
See Section 5.0 Onshore Protection
Consider:
• Exclusion Booming
• Diversion Booming
• Deflection Booming
See Figure For Boom Selection Guidelines

[1] The application of chemical agents such as dispersants is the responsibility of the Federal Government. Although the province, in general, supports the use of dispersants, if their effectiveness can be proven at time of use and their use is proven not to be deleterious to provinced resources, the review of these options is beyond the scope of this manual.

Figure 8. Nearshore Protection Decision Diagram.

response resource information including contacts for oil spill equipment and services, spill response and environmental specialists, guidelines for media and public communication, safety, wildlife rescue, and others.

The BC Physical Shorezone Mapping System (Harper, Howes and Reimer; 1991) defines repetitive coastal types, shoreline residence indices and shoreline treatment options and is used in sensitivity mapping and as a data source for shoreline countermeasures.

SUMMARY

The BC SCAT Manual describes procedures to assess and document oiled shorelines and the process for determining the most appropriate response option(s) for a given section of coast. The SCAT process is founded on the field experience gained and procedures developed during the *NESTUCCA* and *EXXON VALDEZ* oil spill incidents in 1989. The basic procedures are those which have been proven highly successful through actual and extensive use in Alaska. Shoreline cleanup following the *EXXON VALDEZ* depended very heavily on the SCAT reports, advice and database. That information was critical for satisfying communication needs, setting cleanup priorities, selecting techniques, obtaining OSC approvals, for direction to cleanup crews, and for tracking progress. The Environment Canada manual has been written to reflect environments and spill scenarios of British Columbia. A large portion of the Alaska experience has been adapted but considerable new information has also been added. The manual has been written in the context of what can be implemented under various spill circumstances. The manual should not be considered as absolute, but rather describes an approach which is flexible and can be modified to

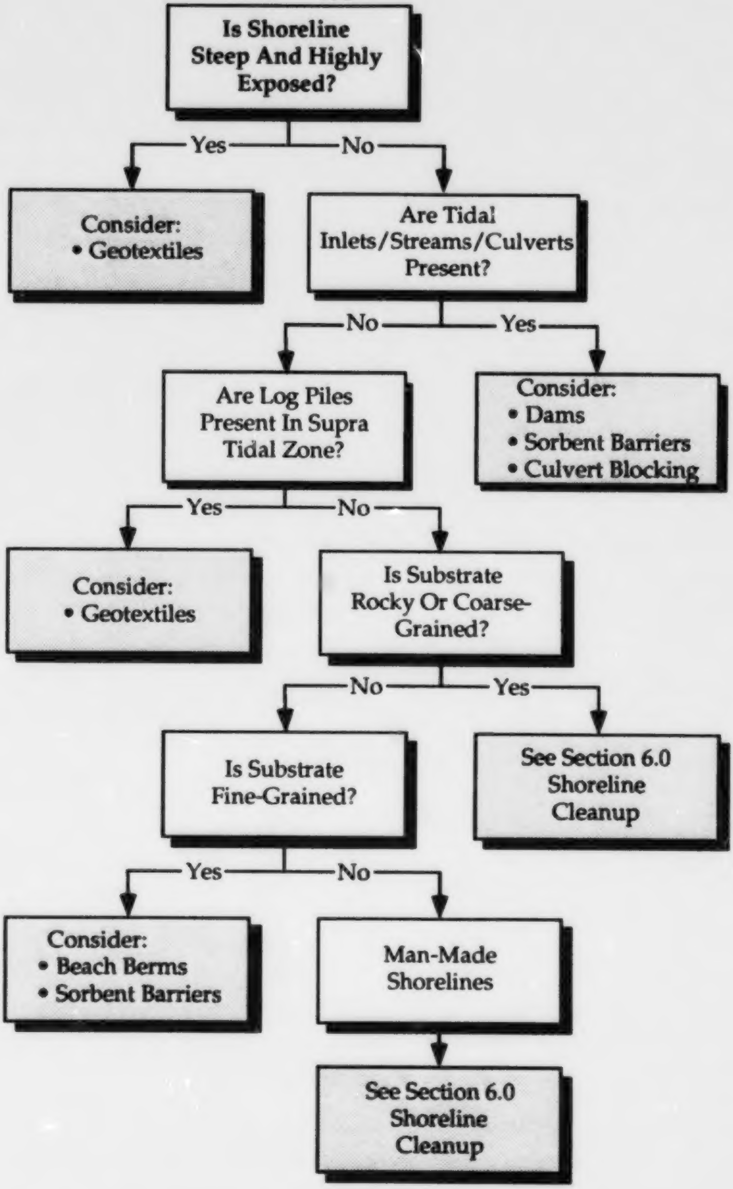

Is Shoreline Steep And Highly Exposed?
Yes
No
Consider:
• Geotextiles
Are Tidal Inlets/Streams/Culverts Present?
No
Yes
Are Log Piles Present In Supra Tidal Zone?
Consider:
• Dams
• Sorbent Barriers
• Culvert Blocking
Yes
No
Consider:
• Geotextiles
Is Substrate Rocky Or Coarse-Grained?
No
Yes
Is Substrate Fine-Grained?
See Section 6.0 Shoreline Cleanup
Yes
No
Consider:
• Beach Berms
• Sorbent Barriers
Man-Made Shorelines
See Section 6.0 Shoreline Cleanup

Figure 9. Onshore Protection Decision Diagram

accommodate the actual spill situation. Although designed for the Pacific northwest, the SCAT process can be applied in a generic manner to other coastal environments.

The BC Shoreline Protection and Cleanup Manual describes the procedures for identifying and implementing the most appropriate protection and cleanup options. The manual is designed to provide decision-making guidelines for determining which protection and cleanup techniques would be most effective for a specific shoreline type and oiling conditions. A detailed discussion of the factors involved in the decision-making process is provided and this includes oil characteristics and behavior, shoreline classifications, protection and cleanup priorities and implementation requirements, and impacts associated with the cleanup operations. The manual describes state-of-the-art spill response techniques for the protection and cleanup of the coastal shorelines of British Columbia. Techniques that are considered experimental or that would not normally apply to the BC shorelines have not been included.

REFERENCES

Harper, J.R., Howes, D.E., and Reimer, P.D., 1991. Physical Shorezone Mapping System for use in Sensitivity Mapping and Shoreline Countermeasures; Proc. 14th Arctic and Marine Oilspill Programme (AMOP) Technical Seminar, Environment Canada, Edmonton, Alberta, (this volume).

Owens, E.H., 1991. Changes in Shoreline Conditions 1 1/2 Years after the 1989 Prince William Sound Spill; Unpublished Report by Woodward-Clyde Consultants, Seattle, WA, 52 pp plus Appendices.

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Owens, E.H., and Teal, E.H., 1990. Shoreline Cleanup following the "Exxon Valdez" oil spill - field data collection within the SCAT program; Proceedings 13th Arctic and Marine Oilspill Programme (AMOP) Technical Seminar, Environment Canada, Edmonton, Alberta, 411-421.

Teal, A.R., 1991. Shoreline Cleanup - Reconnaissance, Evaluation and Planning following the Valdez Oil Spill: Proc. International Oil Spill Conference, San Diego, CA, 4-7 March, Amer. Petr. Inst., Washington DC, Pub. No. 4529, 149-152.

SHORELINE CONDITIONS FOLLOWING THE EXXON VALDEZ SPILL AS OF FALL 1990

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1.0 Abstract

By fall 1990 -- 18 months after the *Exxon Valdez* grounding -- surveys of Prince William Sound (PWS) and the Kenai and Kodiak Region (K-K) of the Gulf of Alaska confirmed that the coastline is essentially clean. Except for a few scattered sections with weathered residue, the survey teams did not find oil on the shorelines and spilled oil was not been seen on the surface during the summer of 1990.

Teams of independent scientists collected data during the first shoreline surveys throughout the summer of 1989. Exxon and Woodward-Clyde consultants presented the scientific findings to the U.S. Coast Guard, the Alaska Department of Environmental Conservation (ADEC) and the interagency shoreline cleanup committee so that decisions could be made concerning cleanup operations. These surveys showed that oil from the accident reached less than 20% of the shoreline in PWS. Oiling was continuous on some stretches of shoreline but scattered in other areas, since the oil slicks broke apart and drifted under the influence of local winds and currents.

Oil from the spill reached K-K over a period of several weeks after the accident, so survey teams in 1989 found mostly weathered residue or oil-water emulsions on the shorelines in this area. Tides and currents stranded oil along less than 15% of the spill-affected shoreline of K-K.

The shoreline surveys of the region, as well as independent Woodward-Clyde/Exxon studies of individual sites, were designed to ensure that cleanup operations proceeded rationally and efficiently. Following one winter of storms and two summers of Exxon cleanup, the joint regional surveys confirmed that the systematic approach had been effective. By the time of the August 1990 joint regional survey, only about 1% of shorelines in PWS and K-K showed evidence of oiling.

2.0 Background

2.1 Introduction

The tanker *Exxon Valdez* spilled approximately 258,000 barrels of Alaskan North Slope crude oil onto the waters of Prince William Sound (PWS) after it ran aground on March 24, 1989. As with any spill of this magnitude in a remote environment, it was virtually impossible to control or contain all of the oil. In Prince William Sound, some of the oil washed onto the shorelines generally southwest of the accident site. Eventually, some of the oil also escaped through the narrow straits that connect PWS with the northern Pacific Ocean and became stranded on shorelines along the Kenai Peninsula and the Kodiak Island-Shelikof Strait region of the Gulf of Alaska (K-K). (See maps 2.1 and 2.2)

To understand fully what happened to this oil in the year and a half after the spill, it is important to understand the geography, geology and ecology of the coasts of this region.

2.2 The Geography of Prince William Sound and the Kenai-Kodiak Region

The cleanup following the spill was strongly influenced by the geography of the region. As discussed later, wave action and tidal flushing play a primary role in the cleanup of shorelines, and the geography of the area dictates levels of wave energy at the shorelines.

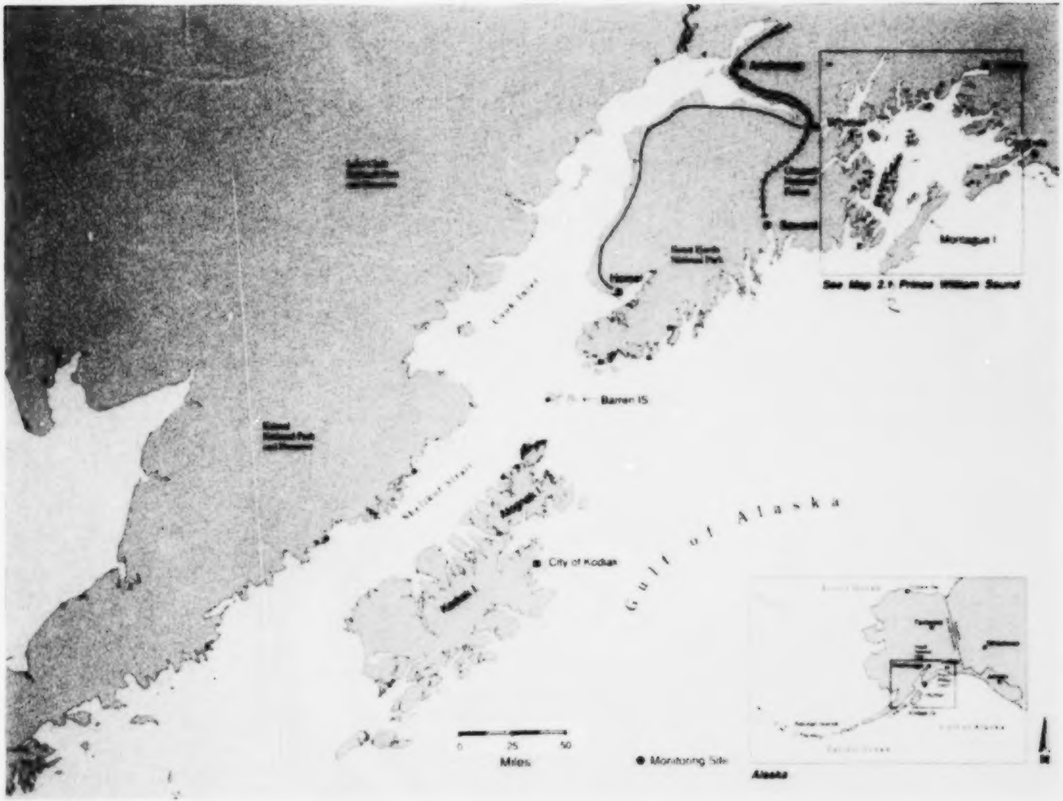
The open ocean coasts of the Gulf of Alaska are an extremely high wave-energy environment. This coastal zone is exposed to the full force of waves from the north Pacific Ocean, and these shorelines rank among the highest wave-energy environments in the world.

In contrast, PWS is a large basin-shaped embayment, or well-flushed inland sea, approximately 100 miles across and connected to the Pacific Ocean by a series of narrow straits. The shape of PWS limits the size of waves. Nonetheless, the area is still subject to wave action from winter storms and wave heights over 6 feet were recorded on exposed coasts in the Sound. In addition, PWS has a tidal range on the order of 10 to 18 feet, and the continually changing water levels spread incoming wave energy over a wide vertical, and sometimes horizontal, intertidal zone.

Wave--energy levels within PWS vary considerably between adjacent sections of coastline. In the western part of the Sound, where oil was washed ashore, there are a large number of islands with numerous bays and passages carved by glaciers during the Ice Ages. As a result, the shoreline configuration is very complex and includes sheltered areas protected from wave action. Unlike sheltered sections of the coast, exposed shorelines receive the full effect of storm-generated waves, and stranded oil is thereby more rapidly abraded and washed from the intertidal zone.

Under normal circumstances, sheltered shores would lag behind exposed ones in the time required for *natural cleanup*. However, in Prince

Map 2.1: Spill Affected Area


Montague I
See Map 2.2: Prince William Sound
Barren IS
City of Kodiak
Gulf of Alaska
0
25
50
Miles
Monitoring Site
Alaska

William Sound, cleanup rates were comparable in areas of both sheltered and exposed coasts. This result, as discussed later, is due to the combination of Exxon's cleanup operations and natural cleansing.

2.3 Geological Character of the Shoreline

The shorelines in the spill area are predominantly rock outcrops or headlands (72%) separated by mixed sediment beaches, which include boulders, cobble, and fine sediments.

Since the majority of the coast is bedrock with intervening pocket beaches, many of which contain fine-grained sediments, stranded oil typically could not penetrate most shoreline surfaces. Even when the oil was generally fresh and mobile, it was confined to the top inch or two of the sediments.

There are only a few areas with very fine-grained sediments (mud and sands) and those occur where there is a local, adjacent source for these materials. This lack of fine-grained material in PWS has resulted in the formation of only a few mudflats and marshes. Within Prince William Sound, only one small muddy area was oiled by the spill.

At a few pebble-cobble beaches, where the fine sands have been washed out by wave action, oil could penetrate more than a foot below the surface. Such beaches, however, account for less than 4% of the coastline. In the same manner that oil penetrated the subsurface so the tide waters are able to penetrate the subsurface, helping to flush out mobile oil from the subsurface of these beaches.

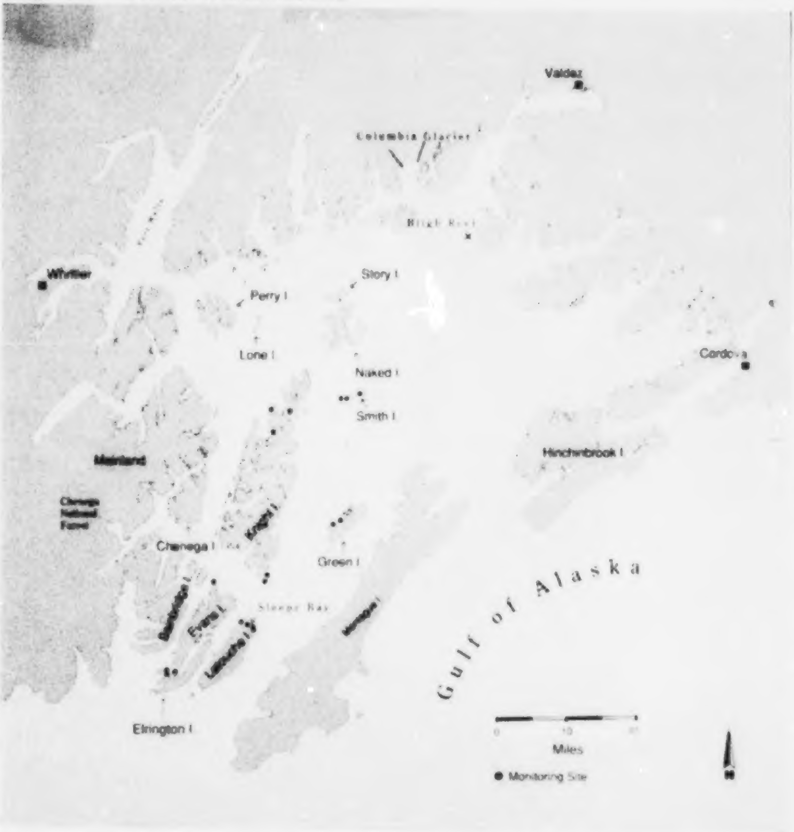
2.4 Shoreline Ecology

The rugged coastal environment supports a very rich and robust intertidal biological community. Life in the intertidal zone is well-adapted to the rocky substrate and the sub-arctic environment. Each species has its own environmental requirements and life history. There is great natural variability in both space and time, and geologically similar shoreline types exhibit different mosaics of biological communities.

The region does, however, have a noticeable pattern of intertidal zonation of species. The principal feature of the supratidal zone, which is above most wave action but within the splash zone, is a band of black lichen. (The lichen is often confused with stranded oil by casual observers). The upper intertidal zone is usually barren or sparsely populated by species that are more common in lower tidal zones. In contrast, the mid- and lower intertidal zones are rich with life, characterized by barnacles, snails, limpets and rockweed. The zones can also be occupied by mussels or by a variety of brown, green and red algae and contain a number of large grazers, scavengers and predators such as chitons, crabs, anemones, whelks, starfish, sculpins and gunnels.

Oil from a spill in this type of coastal environment tends to adhere to the dry, upper part of the tidal zone. The top one-third of the intertidal zone is driest because it is exposed for the longest time and typically is above the zone of groundwater drainage. In contrast, the lower half of the intertidal zone frequently stays wet, even when exposed at low tide, due to water draining out of the beach. Oil can reach the supratidal zone only when high spring tides or storms with high breaking waves move oil or oiled sediments above the mean high-tide level.

Map 2.2: Prince William Sound


Valdez
Columbia Glacier
Bligh Reef
Whittier
Story I
Perry I
Lone I
Naked I
Smith I
Cordova
Hinchinbrook I
Mainland
Chugach National Forest
Knight I
Chenega I
Green I
Gulf of Alaska
Sleepy Bay
Bainbridge I
Evans I
Latouche I
Montague I
Elrington I
0
10
20
Miles
● Monitoring Site
N

3.0 Spill - Affected Areas in 1989

3.1 Survey Methods 1989

Following the spill, two separate techniques were used to map the distribution of oil on the shorelines (Teal, 1991). Immediately following the accident, Exxon initiated reconnaissance surveys using helicopters flying at slow speeds and low altitudes during low tides. One geologist color videotaped the intertidal zone and recorded a detailed audio commentary on the shore-zone character and oiling conditions. A second geologist sketched the oil conditions on flight-line maps and noted the aircraft location. From this information oil cover maps were produced, which then were used to direct the initial cleanup operations. Over 5,000 miles of shoreline were quickly assessed using this technique.

Teams of independent scientists also surveyed the shoreline from the ground. Although this "ground-truth" effort took longer than the video mapping, these Shoreline Cleanup Assessment Teams (SCAT) obtained more detailed information to guide decisions about cleanup and treatment. The SCAT geologist from Woodward-Clyde divided the coast into alongshore segments and systematically collected data on the physical shoreline character and on the distribution and character of any stranded oil. The geologist drew field sketches and described in detail how each segment had been affected by the oil.

Other team members gathered data for the coastal ecology and the cultural-archaeological resource protection components of the programs. For example, the intertidal ecologist generally characterized the biota and recommended constraints to minimize the effects of treatment activities on sensitive communities. The archaeologist identified cultural and historical features of the shore zone to prevent disturbance of these resources during field operations.

All of this SCAT data was used as the U.S. Coast Guard approved the cleanup strategy for each shoreline segment. The strategy was developed by Exxon with input from ADEC and other governmental agencies. Exxon completed all work specified by the U.S. Coast Guard by September 15, 1989. Exxon returned in 1990 for further cleanup. By September 1989, the SCAT surveys had covered over 3,400 miles of coast, including all of the affected areas. Each segment was categorized according to the width of oil bands:

Heavy -- wider than 6 meters,

Moderate -- 3 to 6 meters,

Light -- less than 3 meters wide,

Very Light -- any width with sporadic oiling
(i.e., scattered tar balls or splashes of oil),

Unoiled -- no observed oil.

At the command center in Valdez the SCAT data was entered into a Geographical Information System (GIS), which provided on-site information management. This data set served as the basis for all subsequent comparisons of shoreline oiling conditions.

3.2 1989 Oiling -- Prince William Sound

The SCAT field surveys documented varying degrees of oiling on 486[1] miles of coast in PWS -- or about 16% of the approximately 3,000 miles of shoreline which includes inlands and bays. Oiling was continuous on some stretches of shorelines but scattered in other areas. The field teams classified 145 miles as *heavily* or *moderately* oiled. Another 341 miles were either *lightly* or *very lightly* oiled.

Although this report uses mileage figures for convenience, such figures overstate the extent of oiling. In general, length alone is not particularly meaningful as a measure of actual oiling conditions (Sergy, et al., 1991). Length is a measure that is useful for operations and logistics planning, but oil--cover data obtained from surveys of a beach (such as data discussed in Section 5) provide a more meaningful index.

The shoreline oiling in Prince William Sound was limited to the southern and western areas, due to a prevailing counter clockwise, southwest setting current in the western half of the Sound (Royer, et al., 1990). The majority of the shores that were most affected were within 20 to 75 miles of the spill site. No oil was carried to the shorelines in the northern or eastern portions of PWS.

As the oil moved toward the southwest, the north-facing coasts nearest the spill received a continuous cover of relatively fresh, mobile oil in the upper half of the intertidal zone. South-facing coasts often remained oil-free, even those nearest the spill site, such as Smith and Seal Islands. At distances more than 30 miles from the accident, the oil was more weathered and its distribution was usually discontinuous; many sections of coast on the south and west of Knight Island were not oiled at all.

The potential for subsurface oiling in 1989 was limited by the predominant beach types, as shown in Table 3.3. Only pebble-cobble beaches without fine sediments, less than 4% of the total oiled shoreline length, are susceptible to penetration from this type of oil more than a few inches deep. About half of these beaches are located on exposed coasts, which are naturally cleansed by waves. In sheltered areas, only about 2% of the affected coast are pebble-cobble beaches without fine grains that infill the pore spaces.

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[1] Prior to the completion of the SCAT survey, Woodward-Clyde had compiled results from the reconnaissance aerial video survey to provide input to the initial summer 1989 cleanup plan and to develop cleanup priorities. The aerial video survey identified 357 miles of oiled shoreline in PWS. The ground-based SCAT survey identified additional miles, particularly of very lightly oiled shoreline.

Table 3.1: 1989 Oiling of Prince William Sound (based on ground SCAT survey)

Degree of Oiling	Beach Width Affected	Total Miles
Heavy	> 6 meters	87
Moderate	3 to 6 meters	58
Light	< 3 meters	202
Very Light	any width with <10% cover	139
		486

898 miles surveyed.

Table 3.2: 1989 Oiling Kenai-Kodiak Region

Degree of Oiling	Beach Width Affected	Total Miles
Heavy	> 6 meters	26
Moderate	3 to 6 meters	31
Light	< 3 meters	58
Very Light	any width with <10% cover	703
		818

2494 miles surveyed.

3.3 1989 Oiling -- Kenai-Kodiak Region

For several weeks following the spill, currents and winds carried oil out through the straits that connect PWS with the Kenai-Kodiak region of the Gulf of Alaska. Oil from the spill weathered at sea, so survey teams in K-K found mostly tarry residue or oil/water emulsions on the shorelines. They estimated some degree of discontinuous oiling along 818[2] miles -- or about 13% of the 6,000 miles of shoreline in the spill-affected area of K-K. Teams categorized 57 discontinuous miles as *heavily* or *moderately* oiled and 58 miles as *lightly* oiled. In addition, 703 miles were classified as *very lightly* oiled. This very light oiling was sporadic, and more than 90% of the miles in this category were not actually oiled.

The open coast of the Gulf of Alaska did not receive very much oil, and much of the oil that washed ashore on these open coasts was removed by wave action within a matter of days. Occasionally, oil drifted into sheltered bays or coves and washed ashore. Along the Kenai Peninsula, the east-facing bays and headlands, such as Gore Point and Tonsina Bay, were typically the only ones oiled, as the oil drifted from east to west under the influence of the Alaska Coastal Current (Royer, et al., 1990). Although the total length of affected coastline in K-K was greater than in PWS, the oiled sections were patchy and scattered among long stretches of clean shoreline. As the oil was thicker and more viscous, it rarely penetrated below the surface sediments in the Kenai-Kodiak region.

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[2] Prior to completion of the SCAT survey, Exxon estimated 732 miles of impacted shoreline to develop the initial summer 1989 cleanup plan and to prioritize shoreline treatment for the K-K region.

Table 3.3: Potential for Oil Penetration as a function of Shoreline Character in PWS

Exposed Coasts			
	Shoreline Characteristics	**Percent of Affected PWS Coast**	**Relative Potential for Oil Penetration**
Bedrock	Rock alone is not as common as rock with a rubble (boulder) veneer	32%	none
Mixed Sediments	Often a surface layer, or armor, of large cobbles; with fines filling spaces in subsurface	12%	Limited to a few inches
Pebble-Cobble	Open spaces between particles	1.5%	High
Sand	Well sorted, fine-grained	0%	Limited to surface inch or two
Sheltered Coasts			
Bedrock	Bare rock is found at headlands, elsewhere usually occurs with a rubble veneer	40%	none
Mixed Sediments	Usually a surface layer of coarse material resting on mixed fine and coarse sediments	12%	Limited to a few inches
Pebble-Cobble	Open spaces between particles	2%	High
Sand	Well sorted, fine-grained	0%	Limited to surface inch or two
Marsh-Mud	Mud and Silt	<1%	No penetration

Accessible to rapid wave washing and abrasion

very small percentage of beaches affected.

4.0 Remaining Evidence of Oil - 1990

4.1 Survey Methods -- 1990

The latest available data on shoreline conditions in PWS and K-K come from two separate regional surveys: a Spring Shoreline Assessment Team (SSAT) survey conducted in April, 1990 and a survey conducted in August, 1990 (the August Shoreline Assessment Program or ASAP). Both efforts were conducted jointly with participation from federal agencies (the U.S. Coast Guard and the National Oceanic and Atmospheric Administration) and state agencies (the Alaska Department of Environmental Conservation and the Alaska Department of Natural Resources), the land owner representatives.

The SSAT survey, with 20 teams working simultaneously, covered, on foot, all of the shorelines that had been treated in 1989. The primary purpose of the survey was to support the planned cleanup operation by recording oiling conditions after natural cleanup during the winter months. An important element of this survey was that the agency and landowner representatives were able to see the shoreline sites and oiling conditions at the same time as the field scientists. Each team report included detailed shoreline descriptions prepared by the field scientists and comments by the individual representatives, as well as wildlife observations.

During the SSAT survey, teams dug more than 5,000 pits to evaluate potential oiling at subsurface depths greater than 6 inches. At each shoreline segment they searched for subsurface oil at locations where team members believed oil would most likely be found.

Although the 1989 system for classifying the oil distribution on the shoreline was adequate at that time, a different system was needed for the 1990 SSAT and ASAP surveys. By 1990, natural cleansing and cleanup operations had changed the character of the oil and made its distribution less uniform. It is not always possible, as a result, to make comparisons between 1989 and 1990 categories. A *"heavy"* rating in 1989, for example, is not directly comparable to the *"wide"* rating in 1990. The *"heavy"* classification indicated a continuous covering of relatively fresh oil, whereas the *"wide"* classification involves a 50% or greater covering of weathered residue greater than 6 meters wide.

The ASAP survey documented changes in oil conditions resulting from 1990 summer treatment programs and ongoing wave action. It focused on areas that were treated in 1990 but did not assess all of the oiled areas in the *narrow* and *very light* categories. The results of the 1990 surveys present the changing shoreline conditions over the entire study area and confirm the general pattern of recovery.

4.2 Surface Oiling -- Fall 1990

The oiled shoreline lengths noted in the tables are expected to have dropped significantly over the 1990-1991 winter months as waves and tides continue to clean the shorelines.

Prince William Sound

Following the 1990 cleanup operations, the ASAP survey identified 44.6 miles of oiled shoreline in PWS, with 10.6 miles in the *wide* or *moderate* categories.

ASAP did not cover all of the coasts visited in 1989 or spring 1990, but teams did survey the majority of the *wide* and *medium* shorelines (see Figure 4.1 for a comparison of the common miles). The intention in this survey was to focus on shorelines that might still require treatment in late 1990 or 1991. The results, nevertheless, indicate the scale of the remaining oil distribution.

Kenai-Kodiak Region

Outside of PWS, the 1990 ASAP survey documented 26.1 miles of shoreline with some evidence of surface oiling. Only 2.6 miles fell in the *wide* or *medium* categories of 1990 as compared to 57 miles in the *heavy* or *moderate* categories in 1989.

4.3 Subsurface Oiling -- Spring 1990

As noted above, subsurface oiling was not extensive in 1989. It was not present on most of the sheltered, lower wave-energy beaches, as these contain fine-grained sediments (sands) that prevent penetration of oil beyond the upper few inches. Because of natural cleansing and cleanup operations, subsurface oiling was even less common in 1990. Where subsurface oil remained, it has not significantly interfered with biological recovery (NOAA, 1990).

Prince William Sound

Figure 4.2 illustrates the portion of the originally oiled shoreline within PWS where subsurface oil could be found in spring 1990. On 1.8% of the affected shoreline, oil was present at depths greater than 12 inches (up to a maximum of about 40 inches). At another 1.6% of the affected shoreline, residue could be found at depths of 4 to 12 inches. Subsurface oil was not present along nearly 97% of the shorelines in the previously oiled areas.

Kenai-Kodiak Region

Oil from the spill rarely penetrated the surface of the Kenai--Kodiak Region because it had formed into mousse or tar-like residue which remained on the surface because of its viscosity.

Table 4.1: 1990 Oiling in Prince William Sound Observed During the ASAP Survey

Degree of Oiling	Beach Width Affected		Percent Oil Cover	Total Miles
Wide	> 6 meters	and	>50%	4.3
Medium	> 6 meters	and	<50%	6.3
	or			
	3 - 6 meters	and	>10%	
Narrow	< 3 meters	and	>10%	10.6
Very Light	Any amount		<10%	23.4
				44.6

89 miles surveyed.

Table 4.2: 1990 Oiling in Kenai -- Kodiak Region Observed During the ASAP Survey

Degree of Oiling	Beach Width Affected		Percent Oil Cover	Total Miles
Wide	> 6 meters	and	>50%	0.1
Medium	> 6 meters	and	<50%	2.5
	or			
	3 - 6 meters	and	>10%	
Narrow	< 3 meters	and	>10%	3.5
Very Light	Any amount		<10%	20.0
				26.1

65 miles surveyed.

4.4 SSAT and ASAP Biological Observations

While visiting the various beaches throughout PWS and K-K, the survey teams noted the presence of intertidal flora and fauna, as well as other wildlife.

Teams observed both new plant and algal growth throughout the region's intertidal zones and colonization of shorelines by barnacles, sea snails, crabs, sea stars, mussels, limpets and other species typical to the area. In August, salmon streams were often filled with spawning adults.

Teams also spotted most of the species represented in the area's vast seabird population: murres, kittiwakes, puffins, sea ducks, and cormorants, to name a few. They noted many bald eagles nesting, fledging and hunting prey.

The teams documented many young and adult marine mammals during the beach surveys. Sea otters, harbour seals and Steller's sea lions were most prevalent. Land mammals were also recorded. For example, Sitka deer, Kodiak bear and smaller mammals were observed during the shoreline evaluation.

Figure 4.1: Comparison of SCAT and ASAP data for Prince William Sound and Kenai-Kodiak where the same segements were surveyed.

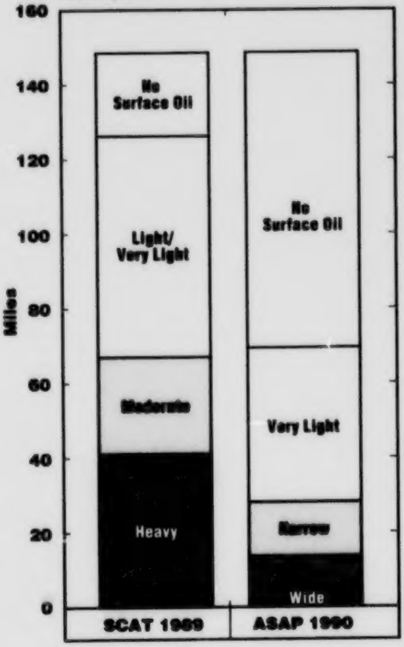
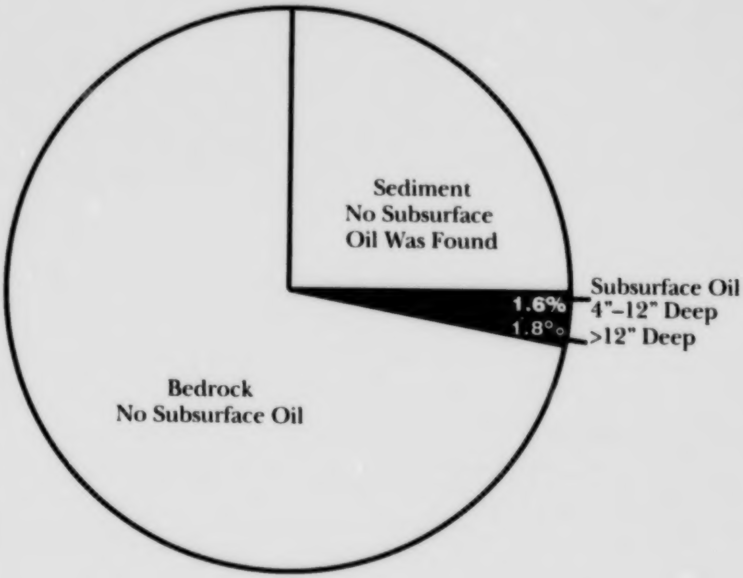


Figure 4.2: Remaining Subsurface Oil in 1990

Based on 3500 pits dug in PWS during the spring 1990 joint shoreline survey (SSAT)



Note: Circumference represents Summer 1989 (SCAT) surface oiling lengths in Prince William Sound (486 miles)

5.0 Cleanup Processes

5.1 Monitoring Program

Woodward-Clyde and Exxon established a detailed long-term scientific monitoring program in May-June 1989. The program involved 28 study sites, 18 of which were located in Prince William Sound. There was a bias in the selection of these study sites, since the monitoring program initially focused on beaches that were the most heavily oiled. The sample included only a few sites that were less oiled; these were in sheltered environments thought likely to recover naturally at a slow rate.

Teams of scientists surveyed the sites regularly for 18 months until September 1990 (Owens, 1991). By that time, the monitoring program had involved approximately 1200 field days of effort (104 days of field work with 4 teams, of 3 people each, operating simultaneously). The program's coastal geologists and ecologists collected information within a standardized framework so that data could be easily compared among sites and through time at the same site. The scientists initially established a set of cross-beach transects at each site and these lines were used to record the distribution of the surface oil cover during repeated site visits.

The monitoring teams surveyed more than 3,000 cross-beach transects to obtain data on changes in the surface oil, and they dug pits to look for subsurface oiling. Transects were also photographed to qualitatively measure biological changes. Among other activities, the team members photo-documented each site, took elevation measurements along transects and collected samples of surface and subsurface sediments for laboratory testing. Time-lapse photography was used at several of the sites to show the changes in beach cover caused by storm and tidal action. The data base from these efforts far exceeds any previous spill study and provides valuable insights into the fate and persistence of stranded oil. Table 5.1 provides a summary of changes in surface oil coverage over an 18 month period.

5.2 Natural Removal of Oil

The results of the monitoring program were not only useful in determining the 1990 cleanup strategy, but they also provide insights into how and why the oil conditions changed at the selected beaches. A number of natural processes work together to remove oil from shorelines following a spill at sea. These natural processes and their role in removing oil from the shorelines of PWS and K-K are described in this section.

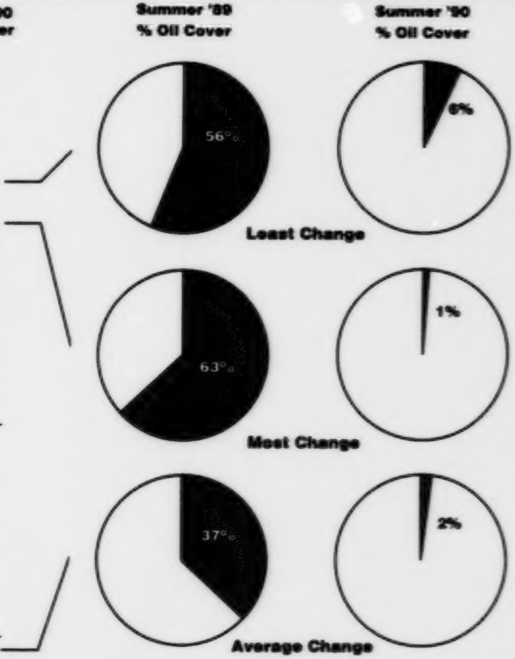
Wave Action and Tidal Flushing

Natural washing and abrasion caused by wave action and tidal flushing were the most important processes by which oil was removed from shorelines in the months following the spill. Waves and twice-daily tides of 10 to 18 feet moved sediment particles to abrade oil and then washed away free or mobile oil particles. The oil released by

Table 5.1: Summary of changes in surface oil coverage for the detailed monitoring sites.

	Monitoring Site	Summer '89 % Oil Cover	Summer '90 % Oil Cover
Prince William Sound	AP-01	79	2
	AP-02	72	6
	AP-04	34	2
	AP-05	43	1
	AP-06	13	1
	AP-07	13	2
	AP-08	56	6
	AP-10	39	3
	AP-11	63	1
	AP-12	70	5**
	AP-13C	73	10**
	AP-13E	63	1
	AP-13W	63	1**
	AP-14	28	0
	AP-15	56	1
	AP-16	27	1
	AP-17	26	0
	AP-18	44	2
Kenai Kodiak Region	AH-01	2	0
	AH-02	23	0
	AH-03	1	0
	AH-04	13	0
	AK-01	71	5
	AK-02	2	0
	AK-03	15	3
	AK-04	27	1
	AK-05	8	1**
	AS-01	12	1
	Average	37	2

**Before Berm Relocation



this process is dispersed into the adjacent ocean waters to be further broken down by natural biological processes.

The rate at which this natural removal occurred was a function of the intensity of wave energy that reached the shoreline, the thickness and depth of penetration of the stranded oil, and the mobility of the beach sediments on which the oil was stranded. Usually, small amounts of surface oil stranded on exposed, high wave-energy coasts washed off very quickly. The more oil that was stranded, the longer the time needed for self-cleaning. On lower-energy shorelines, oil was washed and abraded by wave action during winter storms, when waves would enter the sheltered environments. On these sheltered coasts, the penetration of oil below the surface was restricted by fine-grained sediments among the larger material. The oil, therefore, was accessible to wave action, and the fine sediments acted as an abrasive tool with which even small waves could clean the shorelines.

Mobile oil penetrating cobble beaches that had no fine-grained sediments also was subjected to tidal flushing. As the oil weathered, it became more persistent and was protected from wave abrasion by overlying sediments. However, these sediments were reworked by storm waves which change the beach form (scouring to several feet) and redistribute sediments across the beach.

Biodegradation

Biodegradation is one of the key natural processes which removes oil following a spill. The hydrocarbon-oxidizing microbes create new molecules which are in turn degraded until all that remains are harmless substances, mostly water and carbon dioxide.

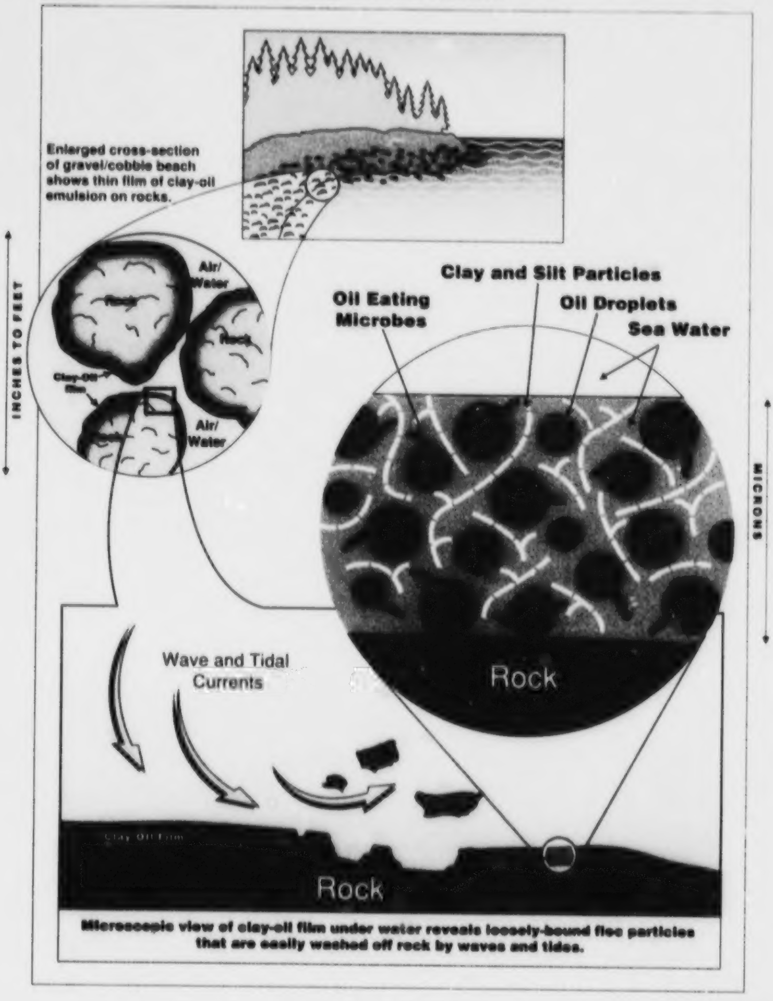
The role of biodegradation becomes a significant weathering factor as wave action and tidal flushing become less effective. The oil-consuming microorganisms work best on thin oil coats or stains on the surface. Biodegradation also plays a significant role in removing subsurface oil.

Clay-Oil Flocculation

A process which was found to be significant in removing stranded oil and which has not been studied on previous spills was the interaction of fine, suspended sediments and seawater with the surface of the oil residue to form solid/liquid emulsions (Bragg, et al., 1990). Micron-sized clay or silt particles, termed "glacial flour," are carried into Prince William Sound waters by rivers fed from the inland glaciers and ice fields. Because of the electrical charges, the fine mineral particles are attracted to, and bond with, the surface of oil films through a flocculation process. This causes the oil to be broken up into very fine emulsion particles containing oil, seawater and mineral fines. Adhesion by the oil particles to the rock surfaces is weakened and the particles are washed away by waves and tidal currents for further biodegradation. (See Figure 5.1).

Field scientists noted in January 1990 that the oil in several sheltered, low-energy environments within PWS had disappeared from rocks and boulders without any evident cause. Meanwhile, in 1989,

Figure 5.1: Schematic of Clay-Oil Flocculation


Enlarged cross-section of gravel/cobble beach shows thin film of clay-oil emulsion on rocks.
INCHES TO FEET
Rock
Rock
Rock
Air/ Water
Air/ Water
Clay-Oil film
Clay and Silt Particles
Oil Eating Microbes
Oil Droplets
Sea Water
MICRONS
Rock
Wave and Tidal Currents
Clay Oil Film
Rock
Microscopic view of clay-oil film under water reveals loosely-bound floc particles that are easily washed off rock by waves and tides.

samples of oiled sediments and nearshore seawater had been shipped in late fall to Exxon's research laboratories for bioremediation studies which used columns that simulated rising and falling tides. Under the laboratory conditions, clay-oil flocculation was observed to break down the oil into minute particles which were easily washed away from the sediments by simulated tidal flushing. Careful inspection of field samples then confirmed clay-oil flocculation as the process responsible for oil removal.

By the first half of the winter of 1989/90, clay-oil flocculation had contributed to the cleaning at many of the rocky and boulder shorelines in the sheltered areas of Prince William Sound. Although the flocculation process also occurs in high energy shorelines, the relative significance of this process is greater in lower energy areas and in subsurface sediments where storm waves and abrasion are less effective.

As with the other natural cleansing processes, clay-oil flocculation works to remove oil from the subsurface as well as the surface (Jahns, et al., 1991). Again, this process promotes biodegradation by exposing a larger surface area of the oil to microbes and oxygen.

5.3 Exxon Cleanup Program

5.3.1 The 1989 Program

Based on an understanding of natural cleansing processes from studies of earlier spills Exxon selected methods that would enhance the natural processes during its shoreline treatment program (Nauman, 1991).

Flood and Flushing

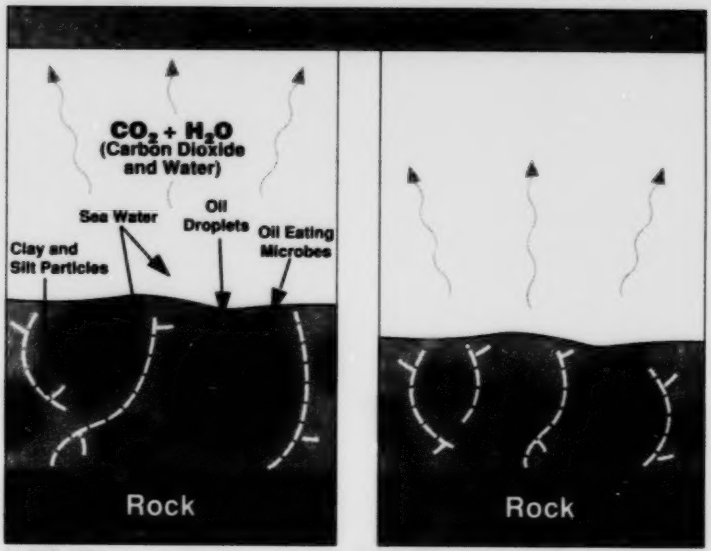
The 1989 cleanup in PWS focused primarily on flushing the free and mobile oil from shorelines, often using heated seawater. The oil that was washed from the shores was contained within booms and picked up using a variety of equipment, including sorbents and skimmers. Flushing was avoided during low tide to keep the lower intertidal free of oil.

By removing the bulk oil, subsequent wave action could be more effective and the area's wildlife would be protected. At the end of the summer of 1989, virtually all of the mobile and free oil had been removed from the shorelines. Comparison of two sites on northern Smith Island, which received different levels of flushing treatments, has been used to assess the success of the 1989 strategy (Owens, 1991).

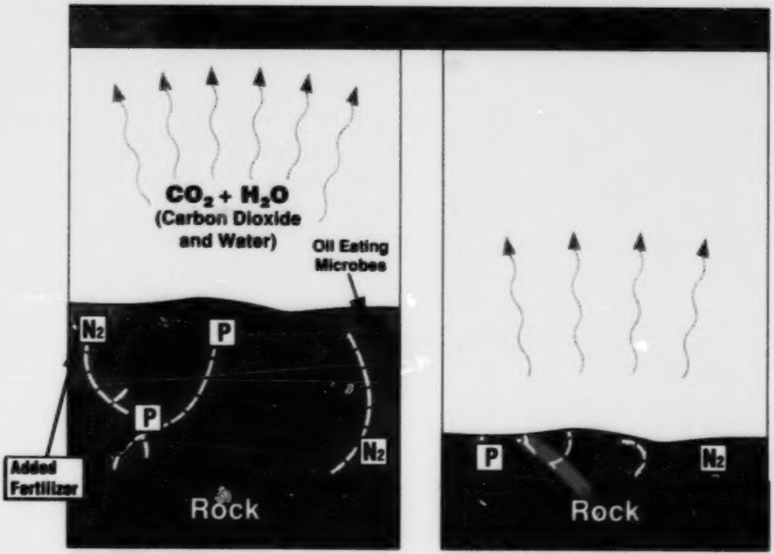
Bioremediation

Soon after the spill, scientists with the United States Environmental Protection Agency (EPA) and Exxon suggested that the cleanup could be accelerated by adding nitrogen and phosphorus to the shorelines so that the indigenous microbes would be able to biodegrade the oil more readily (see Figure 5.2).

Figure 5.2: A microscopic schematic of Bioremediation Process


$CO_2 + H_2O$
(Carbon Dioxide and Water)
Sea Water
Oil Droplets
Oil Eating Microbes
Clay and Silt Particles
Rock
Rock

Initially **3 months later**


$CO_2 + H_2O$
(Carbon Dioxide and Water)
Oil Eating Microbes
N_2
P
P
N_2
Added Fertilizer
Rock
P
N_2
Rock

Add fertilizers **3 months later**

In the summer of 1989, the EPA and Exxon launched a cooperative program to test the capacity of bioremediation to accelerate shoreline cleanup and to ensure that it was an environmentally safe activity. The State of Alaska Department of Environmental Conservation approved widespread use of bioremediation on the basis of the promising test results.

By the end of the summer of 1989, Exxon had bioremediated more than 70 miles of shoreline.

5.3.2 The 1990 Cleanup Program

Wave action over the 1989-1990 winter months, along with biodegradation and enhanced by clay-oil flocculation, considerably reduced the amount of residual oil on shorelines. To cleanup the remaining oil in 1990, Exxon continued using bioremediation, but it also employed other techniques, some of which were not used widely in 1989. A guiding principle was to use non-intrusive techniques which would not interrupt the biological recovery.

Bioremediation

The results in 1989 were so encouraging that another bioremediation program was launched in 1990, when some 400 remaining patches of oiled shoreline of PWS and K-K were treated. A report issued jointly by EPA, ADEC and Exxon estimates that bioremediation typically accelerated natural biodegradation fivefold and occasionally as much as tenfold (Prince, et al., 1990).

Manual Removal

In the spring of 1990, survey teams found residual oil in small patches along shorelines, often behind boulders or in rock crevices. During the summer cleanup operations, much of this oil was removed manually with rakes, shovels and sorbents. In 1989 such manual efforts were largely limited to the tar-like deposits in the K-K region.

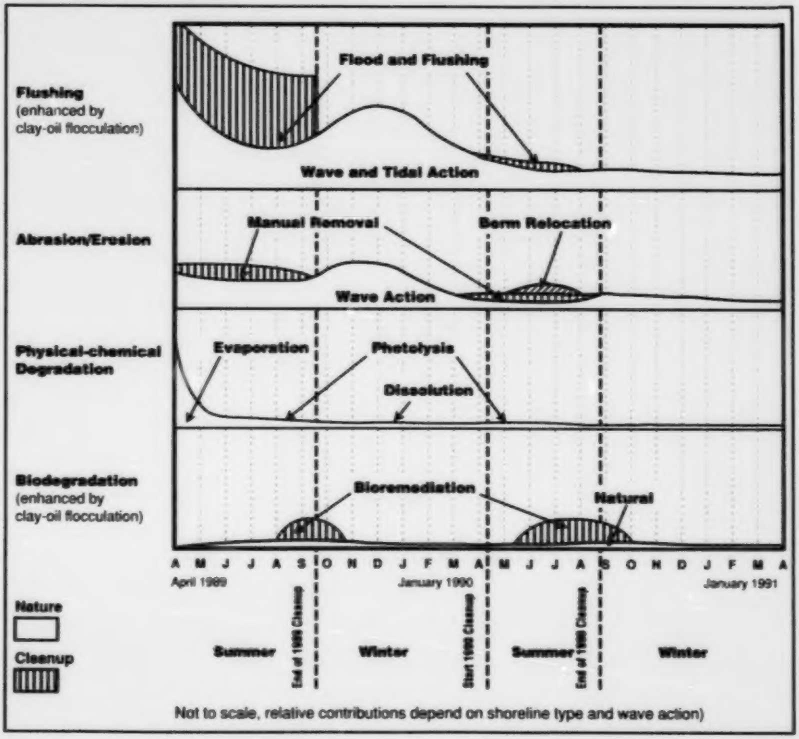
Berm Relocation

Part of the oil which remained after the winter was located on the highest parts of the beach, in the supratidal zone. In these areas, oil had been stranded on the berms above the normal limit of wave action (Owens et al., these proceedings). This residue had been pushed there either by spring tides earlier in the summer of 1989 or by severe storm wave action. This residue remained there through the winter, although it did continue to weather and degrade.

A program to deal with these oiled berms, was developed with approval from the U.S. Coast Guard. Crews relocated the oiled berm sediments back down the beach to expose them to more effective bioremediation and natural cleaning by wave action. This relocation program involved work on approximately 30 beaches and was accompanied by manual pick-up of mousse and tar. The level of effort varied depending on the amount of oil in the berm areas. In a few cases, crews moved more than 1,000 cubic yards of material in order to expose the oiled sediments, allow wave action to abrade, and push the cleaned material back up the beach. At each relocation site, mobile oil was picked up and booms were deployed to contain and collect any oil that might be released onto the nearshore waters.

The 1990 berm relocation activities brought oil residue within reach of wave processes but, as anticipated, also caused a temporary increase in the local surface oil cover. At two of the monitoring locations the surface oil cover had been as low as 5% and 10% in June 1990 but increased to over 25% at the time of September 1990 survey due to the berm relocation program. The activities resulted in the release of only small amounts of sheen, which indicates that the exposed oil had already weathered and become viscous.

Figure 5.3: Contribution of Shoreline Oil Removal by Natural Processes and Cleanup Activities


Flushing
(enhanced by clay-oil flocculation)
Flood and Flushing
Wave and Tidal Action
Abrasion/Erosion
Manual Removal
Berm Relocation
Wave Action
Physical-chemical Degradation
Evaporation
Photolysis
Dissolution
Biodegradation
(enhanced by clay-oil flocculation)
Bioremediation
Natural
A M J J A S O N D J F M A M J J A S O N D J F M A
April 1989
January 1990
January 1991
Nature
Cleanup
Summer
End of 1989 Cleanup
Winter
Start 1990 Cleanup
Summer
End of 1990 Cleanup
Winter

Not to scale, relative contributions depend on shoreline type and wave action)

Following the movement of berm material into the intertidal zone, a beach was bioremediated. In some sections the fertilizers were added several times to replenish the nutrients that help oil-eating microbes degrade oil.

Data from post-relocation surveys in August and September 1990 show a marked reduction in surface and subsurface oiling following this treatment program (Owens, et al., these proceedings).

Tilling

Winter wave action had effectively cleaned most of the oiled subsurface sediments. On some beaches where residual subsurface oil remained after the 1989-1990 winter, the sediments were turned over by tilling and exposed to wave action and bioremediation. ASAP surveys indicate that this effort also accelerated natural cleaning processes.

5.4 Biological Observations

As part of the overall monitoring program, biologists qualitatively examined major intertidal species, such as barnacles, mussels, limpets, snails, green algae and seaweed. Cross-shore transects were surveyed regularly at all of the monitoring sites beginning in September 1989. In June 1990, Exxon increased the number of biological sites to include a range of typical habitats and several unoiled reference sites. This expansion of the program provided data on relative rates of recruitment by the key juvenile organisms, as well as the relative density of juvenile and adult organisms on oiled and unoiled sites.

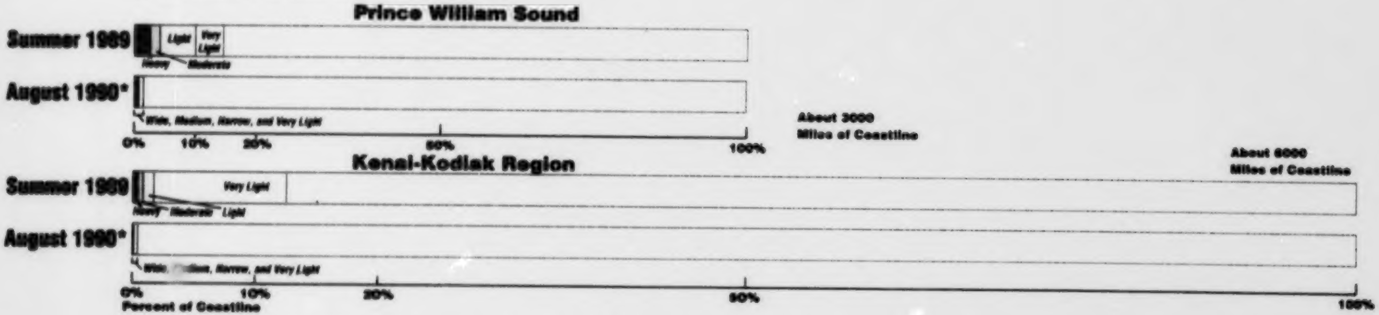
The lower sections of the intertidal zone, which are biologically the richest zones, typically were not heavily oiled during 1989. By the spring of 1990 virtually all of the lower halves of the intertidal zones were oil-free. That oil which remained was predominantly on the highest parts of the beach, where the biota are normally sparse.

The oil spill had adverse effects on the intertidal biota at most monitoring sites, and those effects were still evident one year after the spill. However, the population densities of key organisms usually were not substantially different from those observed on the unoiled reference sites. Recruitment of juveniles was proceeding normally by spring 1990 (Baker, et al., 1990).

Teams did not discover significant mortalities of any intertidal species. Given the apparent extent of biological recovery in the area, it can reasonably be expected that only a biologic expert will be able to discern differences in biota and shorelines by late summer 1991. Despite reported losses in sea otter and seabird populations and short-term damage in the intertidal zone, there are no indications so far of long-term damage by the spill to the Alaskan environment (Dicks, 1990). This is consistent with previous experiences with large oil spills in other areas of the world.

Figure 6.0: Results of 1989 and 1990 Shoreline Oiling Surveys

Profile of Shoreline Oiling: 1989-1990



* The August 1990 surveys covered a fraction of the coast visited in 1989, but did focus on the majority of the more oiled shorelines.

6.0 Conclusions

The latest available data (August/September 1990) from the joint beach-by-beach surveys and detailed monitoring studies indicate:

- The cleanup following the spill has proceeded faster than those following other large oil spills. Exxon crews had successfully removed most of the bulk oil from the shoreline in 1989, which then allowed the natural cleaning processes and Exxon's 1990 efforts to remove remaining oil more rapidly.
- Exxon's use of cleanup techniques such as flushing and bioremediation, caused little environmental damage and accelerated natural cleanup.
- The intertidal zones are biologically active. Intertidal flora and fauna are reproducing and colonizing the previously oiled areas of PWS and K-K.
- Survey teams sighted large numbers of adult and young sea otters, eagles, seals, sea lions, whales, seabirds and other wildlife in the previously oiled areas.

Based on data collected so far, the shorelines are essentially free of oil, only occasional stains and patches remain on a few surfaces. These are found particularly in rock crevices and underneath boulders and cobbles, surfaces which are protected and take longer to clean. In addition, pockets of weathered oil persist under the surfaces of a few beaches. These residues do not pose a risk to the environment (NOAA, 1990), continue to degrade and are not interfering with the biological recovery of the area.

Acknowledgements

The field studies that followed the *Exxon Valdez* spill were, by far, the most extensive ever undertaken to study the fate of oil on shorelines following a spill. The unprecedented project has generated a wealth of data and knowledge about the impact of the oil on shorelines and the effectiveness of the cleanup processes. A project of such magnitude would not have been possible without the dedication and support of many individuals, in particular Exxon program manager Andrew R. Teal.

The hard work and professionalism of the many scientists and technicians who labored diligently during the past 18 months deserve appreciation. I especially wish to thank the more than 50 scientists and engineers from Woodward-Clyde Consultants, as well as the many subcontractors who supported them. The teams spent an aggregate of well over 3,000 labor-days in the field between April 1989 and September 1990. They achieved a perfect safety record, which was no small accomplishment considering that the program continued through the winter of 1989-1990, that shorelines were slippery, and that we constantly used small boats, float planes and helicopters.

Woodward-Clyde senior biologist Dr. Ken Critchlow contributed the sections concerning intertidal ecology. Thanks are also extended to the numerous representatives from the U.S. Coast Guard, the Alaska

Department of Environmental Conservation, and Exxon, whose cooperation was so essential to the success of the project. And finally, acknowledgement is made to Exxon for funding the research that forms the basis for this report.

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BERM RELOCATION DURING THE 1990 SHORELINE CLEANUP PROGRAM FOLLOWING THE "EXXON VALDEZ" SPILL

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ABSTRACT

Regional surveys in the spring of 1990 showed that relatively little oil remained on the shorelines of Prince William Sound and the Kenai-Kodiak region. The oil that did remain was primarily on the highest parts of the beach, above the limit of winter wave action during 1989-1990, or in coarse-sediment beaches, below the limit of wave reworking. An intensive treatment program was developed for 30 sites where the oil remained in sufficient amounts to warrant such action. The program involved movement of oiled sediments from the back-beach areas into the upper intertidal zones, where they could be bioremediated, following recovery of available oil, and reworked by wave action. This sediment relocation also exposes the oiled sediments to tidal flushing and to increased concentrations of nutrients and degrading bacteria. In total, 3000 m of beach shoreline were treated as part of the berm relocation program and this involved the movement of approximately 6000 cubic meters of sediment. Pre-treatment and post-treatment surveys have been conducted to document the changes that resulted from the relocation activities. Based on recent data (April-May 1991), it is evident that the treatment program has been very successful in reducing oil on the study sites and no adverse geological or environmental effects have been found.

INTRODUCTION

The "Exxon Valdez" spilled approximately 258,000 barrels of Alaska North Slope crude on the waters of western Prince William Sound (PWS) after it ran aground on March 24, 1989. The coastline of the Sound consists predominantly of bedrock outcrops and poorly-sorted, coarse-grained sediment beaches. Some of the oil was carried out of the Sound through the straits that connect the Sound to the Gulf of Alaska, where anticlockwise coastal currents moved the oil west and southwest along the coast of the Kenai Peninsula towards Kodiak Island and Shelikof Strait. Shorelines of the Kenai-Kodiak (K/K) region are similar in many respects to those of PWS but are exposed to much longer fetch distances; much less oil stranded in the K/K region than on beaches within PWS.

Treatment of oiled shorelines during the 1989 summer months was designed to remove as much free oil from the environment as possible and to accelerate rates of natural cleaning. Beaches and rock shorelines were washed and oil was contained and collected in sorbents and booms. Those activities enabled physical, chemical, and biological degradation processes to proceed at faster rates than would have been possible with higher oil concentrations. Natural cleaning during the winter of 1989-1990 resulted in further significant reductions in the oil cover on both exposed and sheltered shorelines of PWS and K/K (Owens, 1991).

OIL CONDITIONS IN 1990

A ground survey in spring 1990 assessed the oiling conditions on shorelines of Prince William Sound (PWS) and the Kenai/Kodiak (K/K) region. Data from this survey were used as the basis for decisions on an appropriate treatment program for the 1990 operating season. The survey was carried out by Exxon in conjunction with representatives from U.S. Coast Guard (USCG), National Oceanic and Atmospheric Administration (NOAA), Alaska Department of Environmental Conservation (ADEC), and the uplands landowner. The Spring Shoreline Assessment Team (SSAT) survey was conducted in March and April by 20 teams that collectively surveyed 1952 km of coast (PWS - 1102 km; K/K - 850 km). An additional survey was carried out in June 1990 to supplement the findings of the SSAT program, where the supratidal sediments had been covered by snow at the time of the SSAT survey.

The relatively small amounts of the oil that remained after the winter of 1989-1990 were found mostly either in the supratidal berm areas or in the subsurface of coarse-sediment beaches. Some of the oil had been deposited on the highest parts of a few of the beaches in PWS by spring tides during the early summer of 1989. These oiled sediments were above the limit of normal wave action (abrasion and erosion) and of the daily exposure to tidal flushing (and nutrient/bacteria addition). The second type of residual oil was found at a few sites in the subsurface sediments of coarse-grained beaches. These beaches are not a common feature of PWS, but at some locations oil had initially penetrated through the open pore spaces between the pebble-cobble material, predominantly in the upper third of the intertidal zone. Penetration exceeded the depth of active sediment reworking by wave action over the winter period to spring 1990, so that residual amounts of oil were found on a few of these beaches by the SSAT survey.

TREATMENT OPTIONS

In the spring and summer of 1990, the Technical Advisory Group (TAG), a joint Exxon, federal (USCG and NOAA) and state (ADEC) team, evaluated appropriate treatment methods for each section of coast, based on the shoreline assessment data collected by the spring survey (SSAT). At 30 sites, totalling approximately 3000 linear meters of shoreline, sufficient oil had been located in the berms to warrant sediment relocation and treatment in 1990 (Figure 1 and Table 1). Initially, nine additional berms were considered for relocation, but were later removed from the relocation treatment program. Insufficient oil remained to warrant relocation at five of the sites; ecological concerns precluded work at three beaches, and one was inaccessible. Treatment options considered by TAG included the following techniques:

1) Mechanical Sediment Removal: A possible method to clean oiled beaches is to remove the oiled sediments using earth-moving equipment. A review of data and information from previous spills, however, showed that there are few documented examples of this method of treatment. The only

Figure 1. Location of Relocation Sites

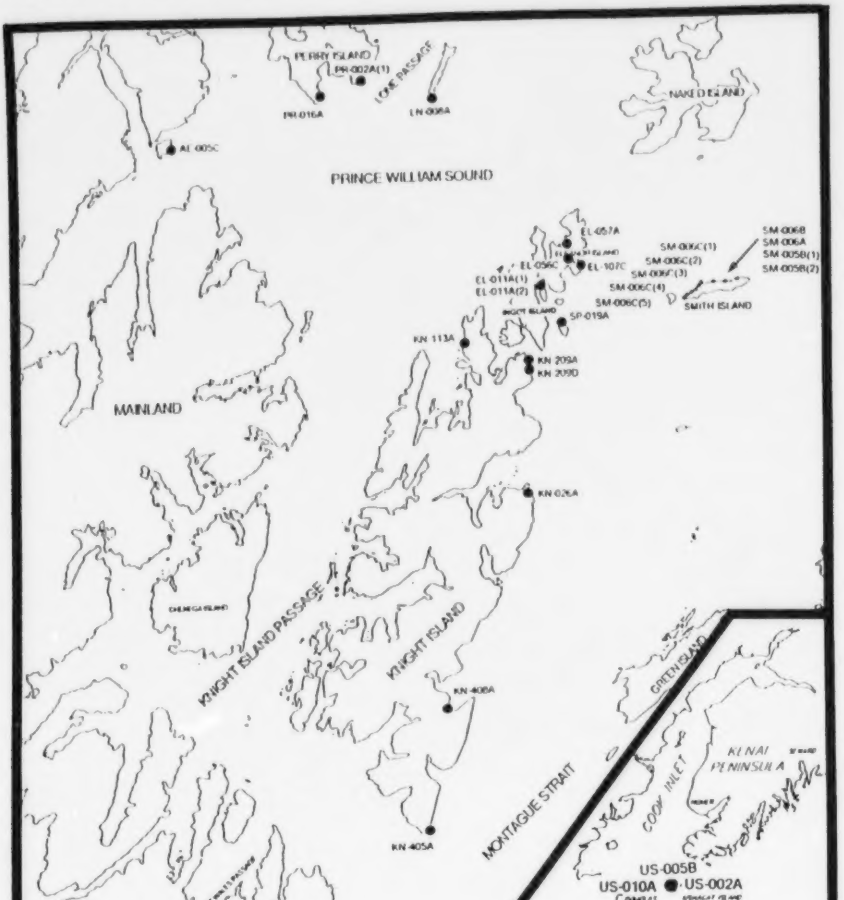
PERRY ISLAND
PR-002A(1)
PR-016A
LONE PASSAGE
LN-008A
AL-005C
NAKED ISLAND
PRINCE WILLIAM SOUND
EL-057A
ELEANOR ISLAND
EL-056C
EL-107C
EL-011A(1)
EL-011A(2)
INGOT ISLAND
SP-019A
SM-006C(1)
SM-006C(2)
SM-006C(3)
SM-006C(4)
SM-006C(5)
SM-006B
SM-006A
SM-005B(1)
SM-005B(2)
SMITH ISLAND
KN-113A
KN-209A
KN-209D
MAINLAND
KN-026A
CHENEGA ISLAND
KNIGHT ISLAND PASSAGE
KNIGHT ISLAND
KN-408A
KN-405A
GREEN ISLAND
MONTAGUE STRAIT
BAINBRIDGE ISLAND
EVANS ISLAND
LA-020A
LA-015C
LATOUCHE PASSAGE
LATOUCHE ISLAND
ELRINGTON ISLAND
KENAI PENINSULA
COOK INLET
US-005B
US-010A
US-002A
GULF OF ALASKA
SHELIKOF STRAIT
KODIAK ISLAND
Woodward Clyde Consultants

TABLE 1. SITE CHARACTER AND RELOCATION ACTIVITIES

Site	Wave Exposure	Sediment Type	Initial Treatment Date	Estimated Volume Relocated (m3)
AE-005C	Intermediate	C,P	6/11/90	R* 4
EL-011A(1)	Intermediate	P,C,G	6/24/90	22
EL-011A(2)	Intermediate	P,C	9/01/90	12
EL-056C	Intermediate	P,G	6/06/90	R* 56
EL-057A	Intermediate	C,P	8/31/90	36
EL-107C	Exposed	C,B	8/31/90	R* 120
KN-026A	Exposed	C,B	6/19/90	T* 15
KN-113A	Intermediate	P,C,G	6/03/90	R* 400
KN-209A	Exposed	C,P,B	6/27/90	250
KN-209D	Exposed	C,P	6/27/90	R* 120
KN-405A	Exposed	P,C,B	6/06/90	120
KN-408A	Intermediate	C,P	5/18/90	T* 130
LA-015C	Exposed	C,B	6/09/90	T* 480
LA-020A	Exposed	P,C,G	6/09/90	T* 540
LN-008A	Exposed	P,C	6/22/90	R* 42
PR-002A(1)	Intermediate	P,C	8/04/90	T* 27
PR-016A	Exposed	P,C	6/26/90	420
SM-005B(1)	Exposed	C,B	6/26/90	130
SM-005B(2)	Exposed	C,B	6/28/90	110
SM-006A	Exposed	B,C	6/25/90	80
SM-006B	Exposed	C,P	6/23/90	T* 68
SM-006C(1)	Exposed	C,B	6/25/90	70
SM-006C(2)	Exposed	C,P	6/25/90	90
SM-006C(3)	Exposed	C,P	6/29/90	36
SM-006C(4)	Exposed	C,P	6/29/90	270
SM-006C(5)	Exposed	C,B	6/29/90	48
SP-019A	Exposed	P,C	6/24/90	R* 40
US-002A	Exposed	C,G	5/29/90	1010
US-005B	Exposed	P,G	7/11/90	51
US-010A	Exposed	C,P	8/31/90	T* 1130

SEDIMENT KEY

B = Boulder = > 256mm
C = Cobble = 64-256mm
P = Pebble = 4-64mm
G = Granule = 2-4mm

* ADDITIONAL TREATMENT

R = Manual raking
T = Mechanical tilling

WAVE EXPOSURE DEFINITIONS:

Exposed = Significant breaking wave heights greater than 1.0 m
Intermediate = Significant breaking wave heights 0.5-1.0 m

08-May-91

case history that was found was from the "Arrow" spill in 1970, where the removal of oiled pebble-cobble sediments from the upper zones of three beaches in Nova Scotia resulted in beach erosion (Owens and Drapeau, 1973). Erosion was documented by pre- and post-treatment surveys along staked cross-beach transect lines (Figure 2). Examples of the effects of the commercial extraction of beach gravels can be found in the literature. One of the most dramatic and well-known is the case of Start Bay, on the southwest coast of England, where coarse gravels were quarried from a pocket beach over the period 1897-1902. The sediments were not replaced by shoreline processes and, during 1917, a combination of spring tides and storm waves destroyed the village of Hallsands (Hails, 1975).

The coastal environments and sediments of the Nova Scotia beaches are similar in many respects to those of Prince William Sound and the Kenai/Kodiak region. Both areas are recently-glaciated environments in which the majority of littoral sediments that comprise the beaches result from the reworking of glacial materials that were deposited in the present-day coastal zone, rather than from contemporary erosion and/or transportation. Similarly, the coarse-grained beach sediments at Start Bay had no modern adjacent source of replenishment.

Most of the beaches in Prince William Sound and the Kenai/Kodiak region have coarse sediments which are supplied to the coastal zone at slow rates or which, in some cases, have no contemporary source of resupply. Thus, removal of oiled sediments from the upper or supratidal beach areas would likely result in (a) net loss of beach material, and (b) re-establishment of an equilibrium beach profile farther landward (i.e., beach retreat or erosion). Based on prior experience and on the evaluation of the sediment transport/supply system in the region, sediment removal was not recommended as a treatment option.

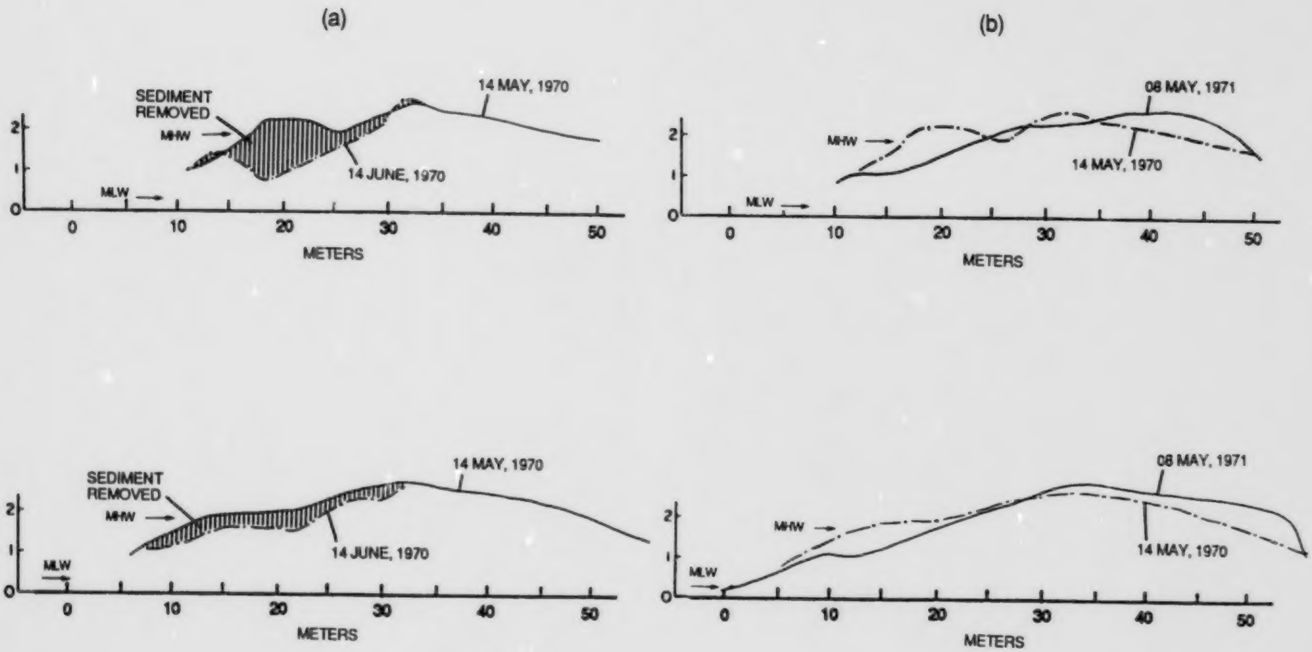

Figure 2. Examples of (a) removal of oiled sediments during clean-up and (b) subsequent beach reatreat on two transects at Indian Cove, Nova Scotia (from Owens, 1972)

2) Sediment Relocation: Oil that has been stranded outside the zone of reworking and cleaning by normal wave action can be relocated to areas where natural cleaning is effective. Most of the oiled sediments that remained in the spring of 1990 were either above the limit of normal or storm-wave action, or were in the subsurface below the zone of wave reworking to date. A report on the cleaning of gravel beaches following the 1970 "Arrow" spill suggested beach relocation and remove-wash-replace methods for this type of oiling (Owens, 1972); one treatment option, therefore, was to move the oiled sediments into areas where they could be treated and wave action could rework, abrade, and wash oil from the sediments. Relocation could be achieved either by pushing material from the backshore down the beach into the upper intertidal zone ("berm relocation"; or "storm berm relocation"), or by tilling the subsurface sediments to bring oiled material to the surface. The advantages of these methods are that they expose oiled sediments for manual removal or bioremediation and make use of natural cleaning processes to remove and disperse the remaining oil for bacterial degradation with no loss of beach sediment.

3) Bioremediation: Biodegradation of surface and subsurface oil by native bacteria can be enhanced by the application of nutrients. Bioremediation is particularly effective after bulk oil removal where the oil is present as a film, stain, or coat (i.e., less than 1 mm thick). This process is less effective in dry conditions, such as exist in the upper part of beaches, where much of the oil that remained in spring 1990 was located (Prince, et al., 1990). As part of the 1989 and 1990 treatment programs, two types of fertilizer were used: Inipol EAP22, an oleophilic liquid that contains 7.3% nitrogen and 0.64% phosphorus; and Customblen, a slow release granular solid that contains 28% nitrogen and 8% phosphorus.

4) Manual Removal: Tar patches or oiled debris had been picked up manually, using shovels and rakes, in 1989. Also, small patches of more mobile oil were removed manually with sorbents. These techniques are

appropriate where the amounts of oil are relatively small and are on the surface of the shorezone, and cause minimal disruption to the coastal environment.

5) Spot Washing: Although washing was the major method by which large amounts of mobile oil were removed from the coasts in 1989, the washing techniques generally were not applicable at the majority of sites that were treated in 1990, as so little oil remained in 1990 and this residue was often weathered and tar-like.

1990 BERM RELOCATION PROGRAM

An initial evaluation of possible treatment options was developed that would minimize disturbance to the beach but would maximize removal and degradation of the remaining oil. These procedures included the manual or mechanical movement of the oiled sediments down the beach (i.e. berm relocation). This treatment was intended to enhance the effectiveness of bioremediation and to make use of normal wave action to rework and abrade the oil and to distribute the cleaned sediments back up the beach. Preliminary recommendations for berm relocation were developed during a joint state-Exxon field trip on 8 May 1990, and were subsequently refined following discussions within Exxon. These procedures were then reviewed with TAG and agreed upon by all parties.

The recommendations that resulted from this process were:

- manually remove surface tar and oiled debris,
- move logs to one side,
- deploy sorbents and booms in the nearshore area to contain any sheens that might be released,
- relocate oiled sediments from the storm berm or neap berm areas to below the neap berm crest, on the upper beach-face slope and above mid-tide level, utilizing mechanical methods wherever possible for maximum efficiency,

- remove any mobile or available oil and, if necessary, string sorbent booms across the relocation area,
- apply bioremediation fertilizers,
- repeat applications if appropriate to provide a continuing source of nutrients for the bacteria.

If subsurface oil is present in the area of relocation, then:

- till subsurface oiled sediments in the upper and middle intertidal zone, to bring them to the surface,
- spot wash and/or till these sediments, if appropriate, to further enhance natural cleaning and degradation rates,
- apply bioremediation fertilizers.

In addition, a number of restrictions on treatment were established. Relocation of oiled sediment to intertidal areas of rich biota and near anadromous streams was prohibited. The treatment procedure recommended against relocation of material above boulder patches, as sediments might be drawn down the beach by waves, infilling the spaces between the boulders. Once within an area of boulders, the sediments likely would remain, protected from wave action by the large clasts. These strategies also avoided damage to epifauna and flora on the boulders.

The recommendations were intended to be general in nature and did not attempt to cover the full range and variety of conditions that were present at each of the sites. These guidelines were supplemented by a series of individual, site-specific recommendations for field operations at each of the 30 beaches where sufficient oil remained to warrant action. The field operations specified for each site were designed to meet the recommendations and constraints developed by the TAG process. The primary constraint was the operational time window, which was defined to avoid disturbance to fish, mammals, and birds. Care was also taken to minimize the risk of creating sheens that could affect sensitive resources, such as hatchery release, fish spawning, or pinniped molting.

SURVEY PROGRAM

A survey program was established to document the oil conditions and the geomorphological effects of berm relocation or tilling treatment. Cross-beach profiles were set up at each berm relocation site to record vertical elevation changes resulting from movement of the sediments. Oil and sediment distribution observations were recorded; these were supplemented with photographic and videotape records. The methods are similar to those that were used for the Fate and Persistence study (Owens, 1991) and five of the detailed study sites set up by Woodward-Clyde in that program were selected for relocation treatment and have a detailed history of oil cover and beach elevation changes. Surveys were conducted:

- prior to 1990 berm relocation or tilling treatment, to record pre-treatment conditions ("pre-treatment survey"),
- shortly after treatment in 1990, to document the immediate effects of the work ("post-treatment survey"), and
- in spring 1991, to evaluate beach conditions following the 1990-1991 winter storm season ("1991 re-survey").

Analysis of the 1991 survey, conducted between 25 April and 5 May, is not complete at the time of this writing and only preliminary results are presented here. During that survey, at 25 of the sites, 79 beach profiles were surveyed to determine elevation changes and 122 pits were dug to define subsurface oil conditions.

Results and observations obtained by other survey programs at some of the berm relocation treatment sites have been used in addition to the results of the berm relocation treatment surveys. Information from the Fate and Persistence program (Owens, 1991) and from regional shoreline surveys, including the 1989 SCAT, 1990 SSAT, 1990 ASAP, and 1991 MAYSAP surveys, have been considered, as well as the preliminary results of a January 1991 NOAA survey (NOAA, 1991) (Table 2).

TABLE 2. SURFACE OIL COVER CHANGES

SITE	SCAT Oil Cover Spring 1989	SSAT Oil Cover Spring 1990	ASAP Oil Cover August 1990	NOAA Oil Cover January 1991	RE-SURVEY Oil Cover Spring 1991
AE-005C	H	M	M	-	-
EL-011A(1)	H	M	M	NO	-
EL-011A(2)	H	M	-	-	-
EL-056C	H	M	M	VL	VL
EL-057A	H	W	-	VL	VL
EL-107C	H	W	-	-	VL
KN-026A	H	W	N	-	VL
KN-113A	H	W	NO	NO	N
KN-209A	H	W,M	M	VL	VL
KN-209D	L	N,VL	VL	NO	NO
KN-405A	H	W	VL	-	VL
KN-408A	H	VL	M,VL	-	NO
LA-015C	H	W	-	VL	VL
LA-020A	H	W,M	N	-	NO
LN-008A	M	N	N,VL	-	NO
PR-002A(1)	L	N	VL	-	NO
PR-016A	H	W	VL	NO	N
SM-005B(1)	H	W	W,M	NO	NO
SM-005B(2)	H	N	N	-	NO
SM-006A	H	W,VL	N	-	NO
SM-006B	H	W,M	VL	-	N
SM-006C(1)	H	W	VL,NO	-	VL
SM-006C(2)	H	W	N,NO	-	-
SM-006C(3)	H	W	VL	-	NO
SM-006C(4)	H	W	VL	-	NO
SM-006C(5)	H	W	W	N	VL
SP-019A	H	M	M	NO	-
US-002A	H	M	VL	-	NO
US-005B	H	VL,NO	VL	-	NO
US-010A	H	M,VL,N	VL	-	NO

SCAT 1989 OIL COVER DEFINITIONS:

H = Heavy = Oil band >6 m wide

M = Moderate = Oil band 3-6 m wide

L = Light = Oil band <3 m wide

1990/91 OIL COVER DEFINITIONS:

W = Wide = Oil band >6 m wide and >50% cover

M = Moderate = Oil band >6 m wide and <50% cover, OR band 3-6 m wide and >10% cover,

N = Narrow = Oil band <3 m wide and >10% cover

VL = Very Light = <10% oil cover, regardless of width

NO = No Oil = No visible oil

- = Not Surveyed

TABLE 3. SUMMARY OF 1991 RE-SURVEY DATA

a) Oil Cover Results - 1990 Pre-Treatment and 1991 Post-Treatment Survey

		PRE-TREATMENT OIL COVER CATEGORY					
		WIDE	MODERATE	NARROW	VERY LIGHT	NO OIL	TOTAL
SPRING 1991 OIL COVER CATEGORY	WIDE	-	-	-	-	-	-
	MODERATE	-	-	-	-	-	-
	NARROW	3	-	-	-	-	3
	VERY LIGHT	8	1	-	-	-	9
	NO OIL	5	2	4	2	-	13
	TOTAL	16	3	4	2	-	25 SITES

b) Changes in Oil Cover by Tidal Zone and Oil Category

OIL COVER CATEGORY	SUPRATIDAL ZONE			UPPER INTERTIDAL ZONE		
	PRE TREATMENT	1990 POST TREATMENT	SPRING 1991	PRE TREATMENT	1990 POST TREATMENT	SPRING 1991
WIDE	14	-	-	12	2	-
MODERATE	3	2	-	1	2	-
NARROW	3	2	3	4	4	2
VERY LIGHT	2	5	3	2	10	4
NO OIL	3	16	19	6	7	19
TOTAL	25	25	25	25	25	25

RESULTS

During the summer of 1990, sediment relocation took place at 29 of the 30 beaches selected and 14 of these sites also were tilled or raked (Table 1). Approximately 6000 cubic meters of sediment were relocated and one-third of this total volume is accounted for on two beaches and another third on a further 4 beaches. Following this work, bioremediation nutrients were applied at all of the sites. The concern that sheens or slicks might be generated and contact local and nearby resources did not materialize. A few small sheens were generated at some sites and these were controlled by the sorbents and snare booms. The general absence of free, or mobile, oil is attributed to a combination of:

- the success of the 1989 treatment program, and
- the fact that the residual oil in the relocated or tilled sediments had been subject to 15 months of wave washing and weathering since the spill.

An expected consequence of the relocation and tilling program was a temporary increase in surface oil cover in the upper intertidal zone at some sites; however, summer wave action had already reworked and redistributed sediments on exposed beaches (Figure 3; Photograph 1).

The largest reductions in oil cover were expected to occur over the 1990-1991 winter months. Preliminary results of the January 1991 NOAA survey and the spring 1991 survey indicate that very little or no oil cover remains at many of the treated sites. Eleven treated sites were studied by NOAA; oil cover data reported for these beaches were converted to SCAT categories for comparison. No oil was found in the supratidal zone at eight of the sites and light or very light oil cover remained at three (NOAA, 1991). Relocated sediments were found to have been cleaned and redistributed during the 1990-1991 winter, as expected; oil cover was found in the upper intertidal zone at only three of the 11 NOAA sites.

Spring 1991 Re-Survey

The 1991 study program involved resurveys at sites where change had been observed in 1990, following treatment, to document any further changes which might have occurred over the 1990-1991 winter months. At the sites that were resurveyed, the number with a wide or medium oil cover was reduced from:

- 14 (pre-survey), to
- 2 (post-survey), and to
- 0 in spring 1991 (Table 3a).

Significantly, the number of sites with a wide or moderate cover in the supratidal zone also was reduced from:

- 21 (pre-survey), to
- 2 (post-survey), and to
- 0 in spring 1991 (Table 3b).

These observations suggest that the winter wave action was very active in terms of sediment reworking, abrasion and redistribution so that very little or no oil cover remains at most of the treated sites.

Geomorphology and Sedimentology

Although the intertidal sections of beaches appear to have eroded over the winter months, as part of the normal annual beach cycle, no backshore erosion due to wave processes was apparent at any of beaches where relocation or tilling was done. Relocated sediments were redistributed back up the beach face at most sites (Figure 4) and at some exposed sites, swash ridges of relocated sediment were observed to have moved up the slope only a few days following treatment (Figure 3).

The changes which were observed and documented in the spring 1991 re-survey, show that, as expected, considerable reworking and redistribution had occurred between the fall and spring surveys, but quantification of this aspect of the study awaits further data reduction. Preliminary results of the

Photo 1

Sleepy Bay (LA-20 A); shortly after completion of relocation a ridge had migrated back up the beach-face slope, 6 August 1990 (see Figure 3).

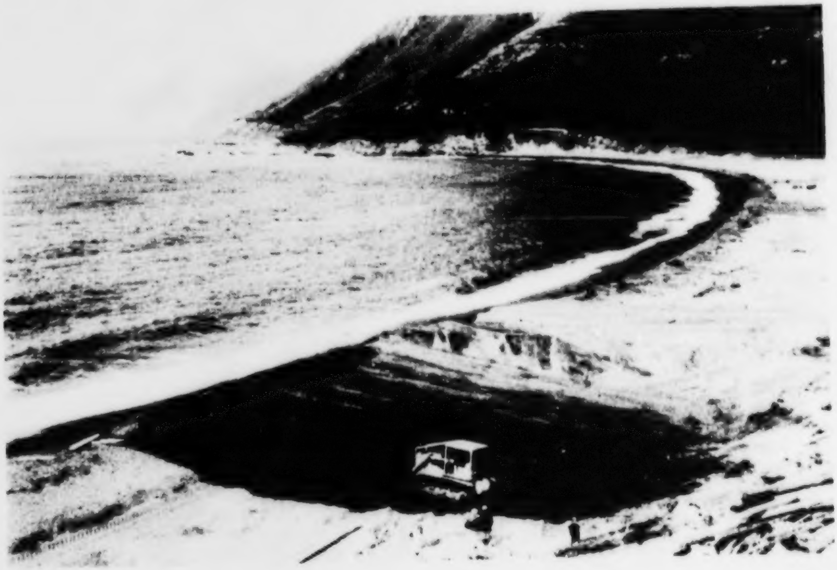

Photo 2

Ushagat Island (US-10 A); relocation of oil towards the top of the beach-face slope, 8 September 1990.

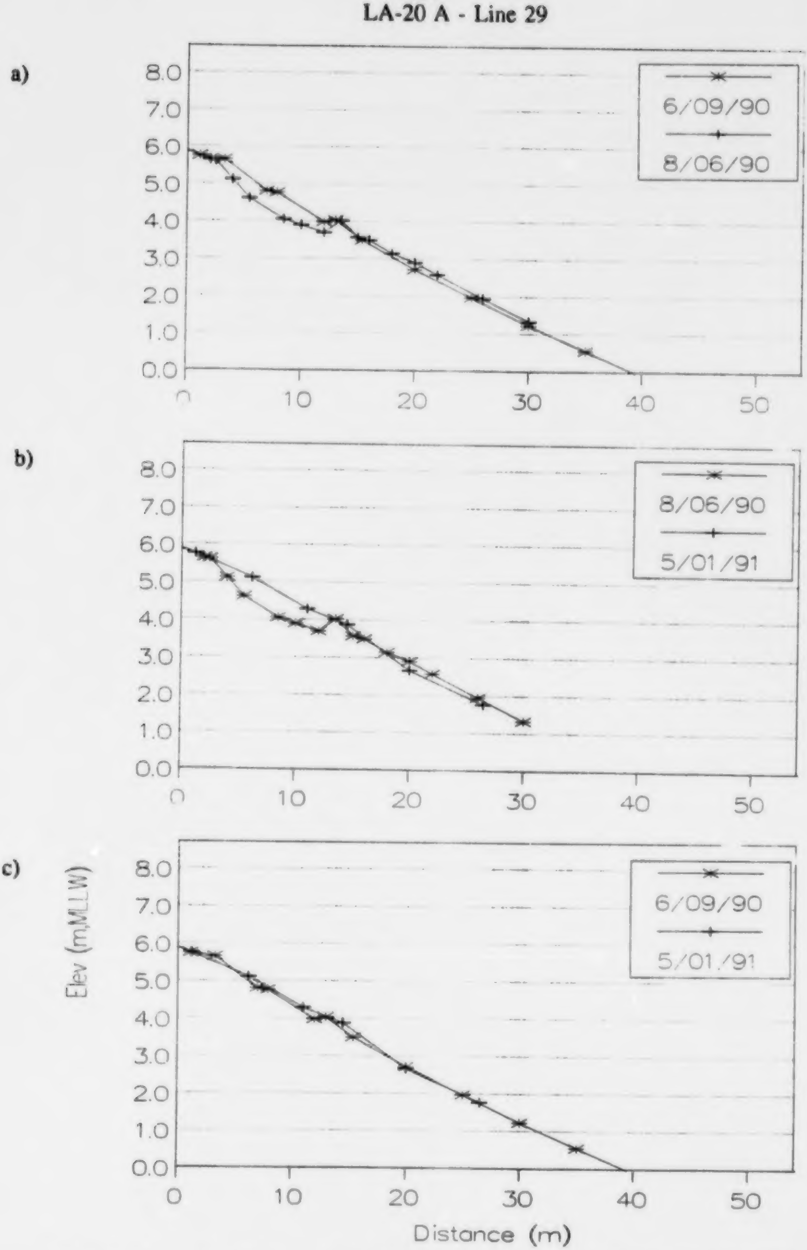

Figure 3. Elevation profiles from Site LA-20 A, line 29. Comparison of (a) pre-treatment and post-treatment, (b) post-treatment and spring 1991, (c) pre-treatment and spring 1991. The ridge at 13 m on the 6 August profile is shown in Photograph 1.

1991 re-survey indicate that 1991 beach profiles at treated sites fall within or above the normal 1989-1990 range, or "sweep zone", for the five sites where sufficient data exists to determine this range.

DISCUSSION

As a result of the relocation program, changes were observed in the surface oil cover of the supratidal and upper intertidal zones and wave action was observed to have redistributed the sediments even before the onset of winter conditions. Preliminary assessment indicates that the treatment program was effective for the oiled berm and subsurface sediments. No large-scale biological effects were observed and this can be attributed to the precautions that were taken to avoid burial of intertidal biota, disturbance of birds and mammals, and the release of sheens.

On-Site Activities

Treatment activities at each site were guided by TAG recommendations and work plans. Treatment and the downslope movement of oiled sediment generally was accomplished according to these operational guidelines; an estimated total of 6000 cubic meters of sediment were relocated at the 30 sites. Two beaches on Ushagat Island (US-2A and US-10A) stand out in terms of the estimated volume of relocated sediments, as approximately 1000 cu.m. were moved on each of these sites (Photograph 2). By contrast, less than an estimated 100 cubic meters were relocated at half (15) of the sites, and at 4 of these, less than an estimated 25 cu.m. were relocated (Table 1). At some sites, close cooperation between the equipment operator and an on-site geologist or technical advisor was needed to efficiently identify and relocate the oiled sediments. Some of the oil remaining in the berm areas prior to treatment was buried below clean sediments, making documented and well-illustrated work plans a necessity, with all reference points clearly marked for the treatment crew.

Site-specific treatment variations were needed at some sites in order to address environmental and physical considerations. At west Ushagat Island (US 10A), in the Barren Islands Group, a variation on the technique was developed so that the sediments would be relocated above the mean high tide to be reworked by wave action only during winter months, thereby alleviating a concern that sheens might affect nearby summer seabird colonies. A subsurface deposit of mousse in the upper intertidal zone of LA-20A was mapped, exhumed, and treated prior to relocation of oiled supratidal sediments. Variant plans were prepared by an on-site geologist or technical advisor and approved by TAG.

Ecological Effects of Treatment Activities

During the planning stage, a primary concern was that the relocation and tilling techniques could cause the release of sheen onto the adjacent waters. Consequently, the field operations procedure involved the placement of sorbents and booms to contain any released oil. During and following treatment, however, few sheens developed. Where sheens were evident, sorbent and snare booms proved very effective and at no time was released oil a concern or a threat to local resources.

A second concern was that sediment relocation would damage the intertidal communities. The pebble-cobble beaches, for which the technique was designed, are characterized by a paucity of species in the upper half of the intertidal zone. The operations procedures, therefore, defined the zone of relocation, in most cases, to be the upper third of the intertidal zone. At some sites, such as US-5B, a lateral and downslope movement was prescribed to avoid burial of surface communities. All relocation and tilling activities were carefully planned to avoid the release of oil or sheen adjacent to anadromous streams, particularly as the relocation activities sometimes coincided with salmon spawning.

LA-20 A - Line 25

(a)

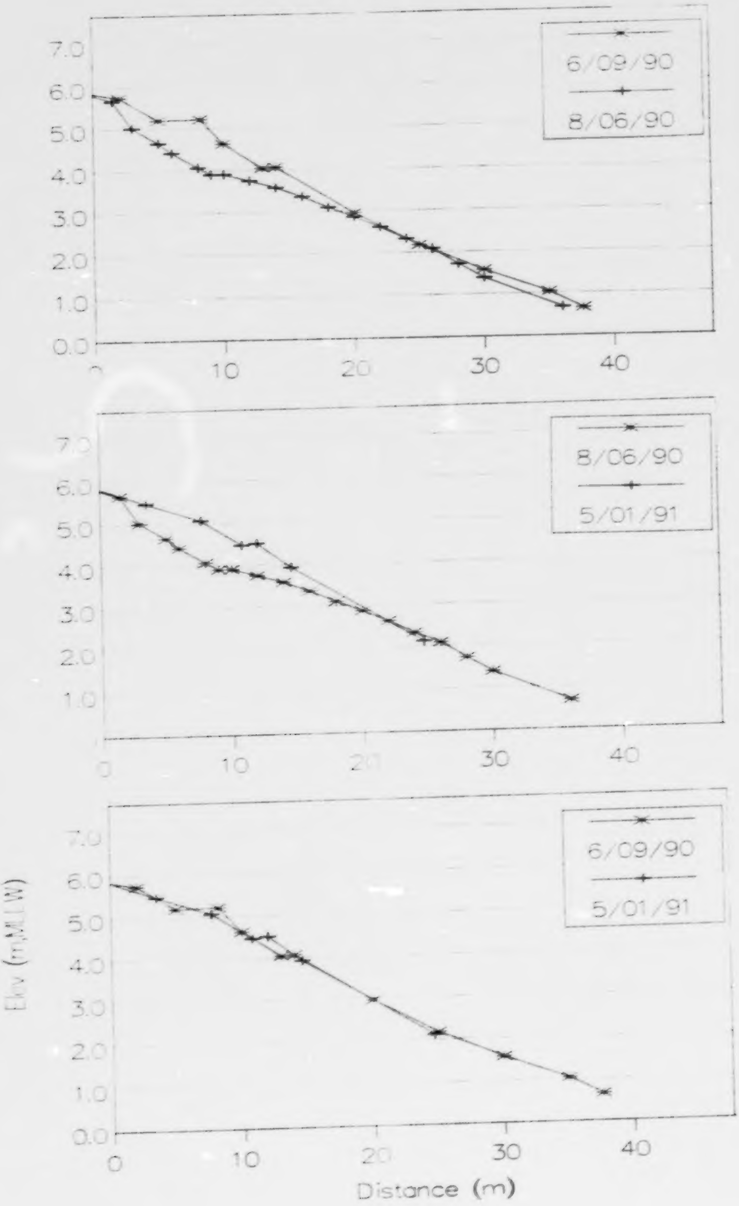

Figure 4 a). Comparison of elevation profiles; pre-treatment and post-treatment (top), post-treatment and spring 1991 (center), pre-treatment and spring 1991 (bottom).

SM-6 C - Line 6

(b)

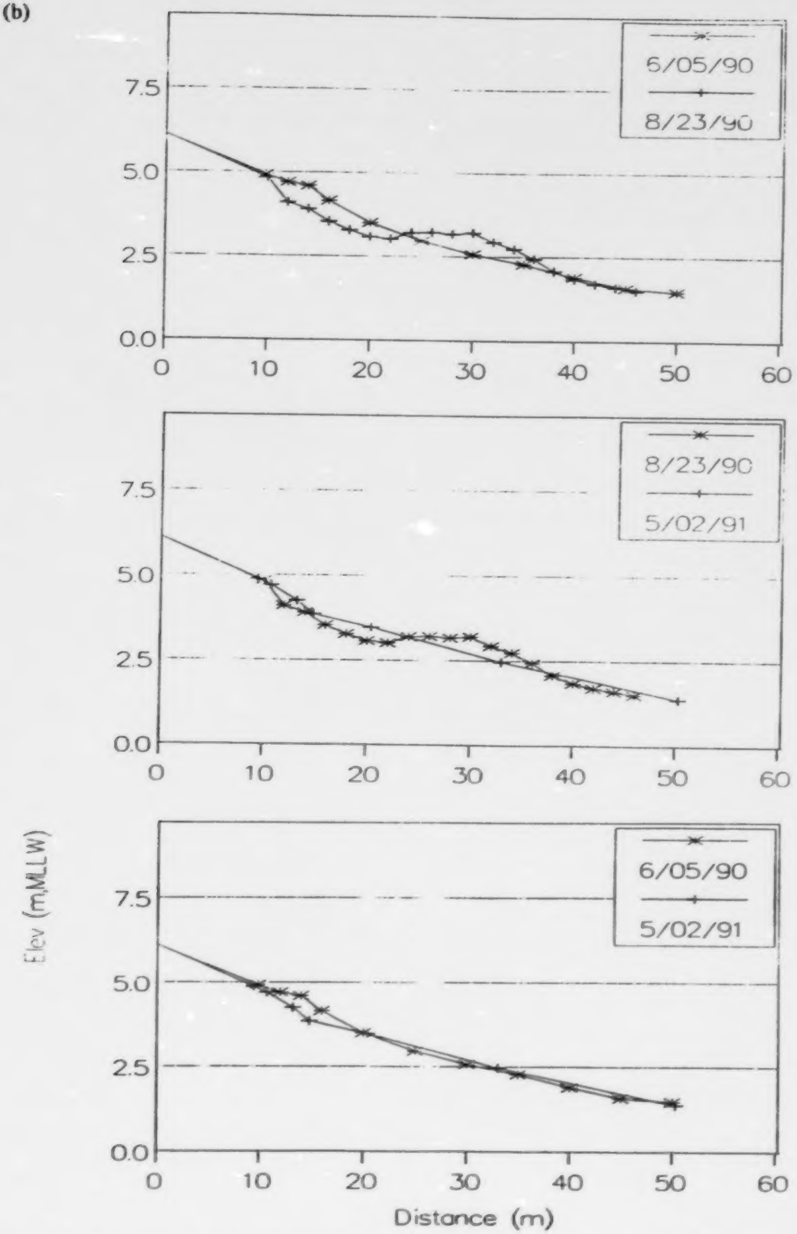

Figure 4 b). Comparison of elevation profiles; pre-treatment and post-treatment (top), post-treatment and spring 1991 (center), pre-treatment and spring 1991 (bottom).

CONCLUSIONS

The relocation of oiled sediments at 30 sites progressed according to the recommendations and work plans developed by the joint assessment team (TAG). This treatment program was part of the overall strategy to reduce the residual oil on the shores of Prince William Sound and the Kenai/Kodiak region. The strategy involved manual removal, relocation, washing, bioremediation, and natural cleaning. Sediments classified as having cover and coat oil characteristics were treated and relocated from berm areas into the zone of wave action. Oil or sheen released from the sediment after relocation or tilling was minimal and was controlled by sorbents and sorbent/snare booms, so that no significant volume of oil or sheen were released onto the adjacent waters. Summer wave action was effective in redistributing the relocated sediments at some of the exposed sites; preliminary observations at eleven sites indicate that most of the relocated sediments were redistributed without apparent net loss by winter wave action and that pre-treatment beach profiles have been rebuilt. Specifically, the results of the spring 1991 survey can be summarized as follows:

Surface Oil Conditions

- "no visible oil" was recorded at 13 sites;
  "very light" (<10%) cover at 9 sites (of which 3 sites had only scattered stains); and
  "light" (0.1 to 3 meters wide) cover at 3 sites
- none of the sites had "moderate" or "heavy" surface oil covers

Subsurface Oil Conditions

- 122 pits were dug and none contained pore spaces that were completely filled with oil; most pits were dug in the supratidal and upper intertidal zones; the highest concentrations found were some heavy oil residue:
  6 pits - partially filled pore spaces
  2 - heavy coat
  4 - light coat
  6 - stain
  14 - oil film
  90 - no visible oil

Beach Conditions

- normal beach profiles have been re-established; most beaches were narrower and steeper than at the time of the relocation program, as "winter profile" conditions were still in effect
- beach armouring has been re-established at all sites where this was present prior to treatment
- neap and storm berms have been re-established by winter wave action
- no backshore erosion, landward of the normal zone of wave activity, was observed
- no anomalous sedimentary or morphological conditions were observed on any of the study beaches; the shoreline profiles and sediment distributions on the study beaches are within the normal variations for these shorelines

Both residual oil in the berm areas and oil cover on relocated sediments have been significantly reduced, meeting the primary objectives of the relocation and tilling treatment program. In total, approximately 3000 meters (or nearly two miles) of beaches in Prince William Sound were treated as part of the berm relocation program; this involved the movement of approximately 6000 cubic meters of material. The program was carried out with due care and attention to the geology and ecology of each site and site-specific work plans were prepared. This approach has resulted in a successful treatment program, in terms of enhancing the natural recovery of the sites, and no adverse environmental changes have been observed.

ACKNOWLEDGEMENTS

The Program Director for this study was A.R.Teal (Exxon Company USA) and the Project Manager was E.H.Owens (Woodward-Clyde Consultants). The monitoring work was performed by WCC scientists under contract to Exxon, who provided all air, vessel, and field logistical support. Field work was conducted by the authors and by B. Trimm, F. Wehrenberg, and G. Williams; data reduction support was provided by A. Sinthusan and J. Young.

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DEVELOPMENT AND TESTING OF A PROTOTYPE ROCKWASHER FOR CLEANING OILED BEACH COBBLES

by

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ABSTRACT

A full-scale prototype cobble washer was tested in early September 1990 at a site in Woodlawn, Ontario near Ottawa. This prototype was designed to be used on remote beaches consisting of cobble, boulder and mixed type sediment. Several criteria including feed material size, simplicity, heli-portability, throughput and power requirements had been set and were met by this prototype.

The following beach sediment and oil types were used in this study: mixed sediment, gravel and cobble oiled with fresh, weathered and emulsified crude and Bunker A, at oil loadings of 0.25 to 2.0% by weight. This study demonstrated the capability of the prototype to effectively clean contaminated beach sediment. Cleaned beach sediment contained 0.00 to 0.02% oil. Cold water washing was adequate for most oil/sediment combinations except those with Bunker A. Bunker A/sediment combinations required hot water washing and usually a second pass through the rock washer. Throughput rates of over 16 tonnes/hour were achieved with this prototype.

INTRODUCTION

Over the last decade much effort has been given to the development of mechanical cleaning systems for contaminated sand beaches. However, an oil spill along Canada's shoreline is more likely to result in the contamination of rocky shorelines.

Few studies have been dedicated to the development of pebble, shingle or rocky shoreline cleanup devices. Recent spill events on Vancouver Island and in Prince William Sound, Alaska, have heightened awareness of the problems associated with cleaning gravel/cobble sediment beaches and resulted in renewed interest in washing techniques.

Objectives

The purpose of this study was to research, design, construct, and test a prototype moderate-capacity, heli-portable, stationary gravel/cobble washer. The objective was to develop a system that could wash oil off gravel/cobble that had an oil loading too low for the use of incineration or was inappropriate for placement in an incinerator.

Goals

More specifically, the project was aimed at achieving the following goals:

- design and build a prototype with readily available materials (i.e., culvert, angle iron, etc.) to the greatest extent possible to permit easy, inexpensive construction of many units in the event of a spill; and
- design and build a prototype to meet established criteria of: feed material size, simplicity, mechanical reliability, heli-portability, safety, throughput, manual loading, power requirements, washwater/solvent requirements and recycling and oil separation.

STATE-OF-THE-ART REVIEW

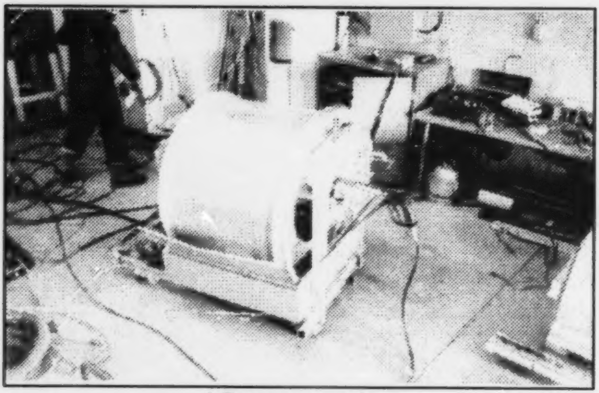
S.L. Ross Environmental Research Limited, in a 1984 study for the oil industry's Canadian Offshore Oilspill Research Association (COOSRA), conducted a detailed survey of the coastline of Canada that identified predominant shoreline types, reviewed available information on shoreline oiling processes, reviewed the state-of-the-art in mechanical shoreline cleanup and identified gravel, cobble and mixed sediment beaches as a key Canadian shoreline type for which no mechanical cleanup systems existed. A gravel washing system was researched, a bench-scale prototype constructed (Figure 1) and tests conducted (Figure 2) with a range of oil types, washwater flowrates and pressures, and sediment sizes (1 cm to 15 cm usually; one test used 25 to 30 cm cobbles). A heli-portable mobile full-scale cleaner was conceptualized, including loading via small heli-portable 4WD tractors, washing, sediment redistribution, oil/water separation, etc. The system, as proposed, supported by several small 4WD tractors, could theoretically clean 22.5 tonnes per hour of gravel/cobble sediment (roughly equivalent to 100 man hours of manual sediment removal). Research on gravel/cobble beach trafficability, additional bench-scale testing, construction and testing of a full-scale prototype was proposed in 1984, but never funded.

The following is a review of available beach cleaning equipment developed since the 1984 COOSRA study.

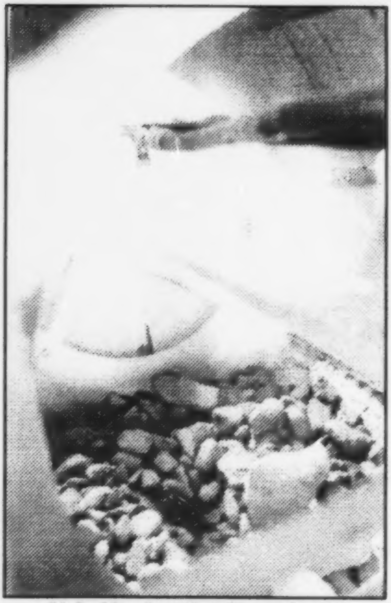
Mobile plant prototype (CEDRE, IFP and LCPC developments)

A research program was undertaken in 1980 with support of the European Economic Community and the French Ministry of the Environment to develop a technique for treating oily beaches. The objective was to define a modular process that could be implemented mainly with available and easily transportable equipment and that would be able to wash polluted sands of variable grain-size distribution at different stages of weathering. As little work had been done in this matter, CEDRE (Centre de Documentation de Recherche et d'Expérimentations sur les Pollutions Accidentelles des Eaux), IFP (Institut Français du Pétrole), and the Laboratoire Central des Ponts et Chausses were asked by the French authorities to evaluate beach cleanup techniques.

An on-site mobile plant prototype for washing oily sand and pebbles was designed and tested in 1985 by these research groups (Bocard et al. 1986). Composed mainly of a horizontally rotating wash drum with a screen, a hydrocyclone to separate the sand from the wash water phase and a vibrating screen for sand dewatering, this unit was mounted on the bed of a semi-trailer along with two transfer pumps. This project involved laboratory and



a) Rotary porous drum



b) Inside view showing rock and
water nozzle

Figure 1: S.L. Ross bench-scale cobble washer

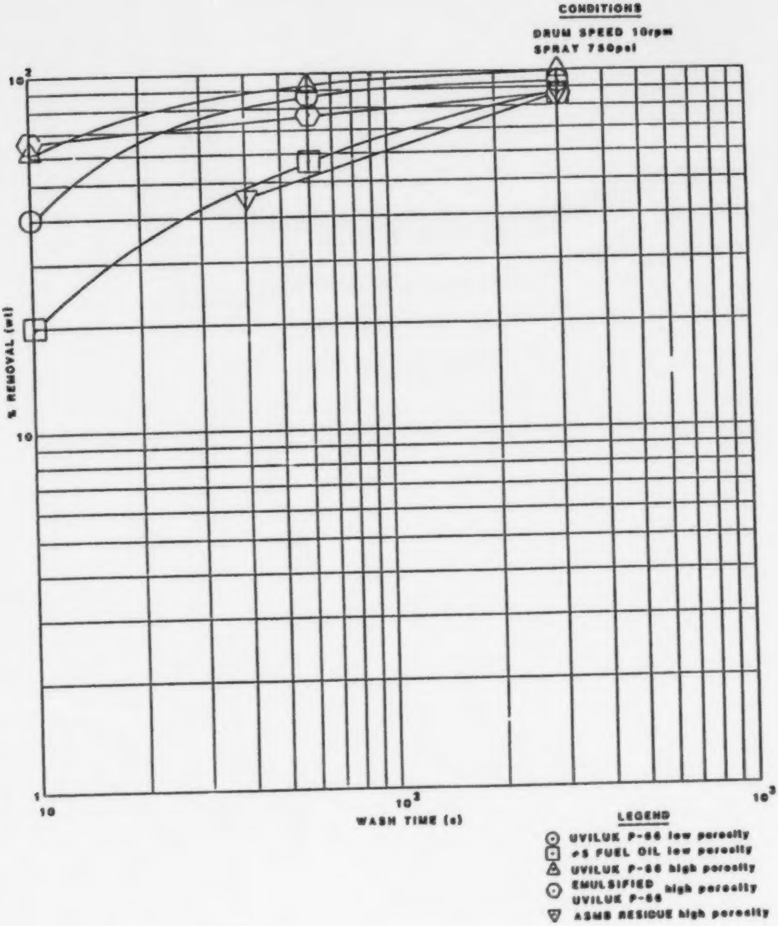


Figure 2: Percent removal vs. wash time

pilot-scale trials to define the process and washing products and to select the equipment, followed by the construction and trial of a prototype with a throughput of 20 tonnes of oiled sand per hour.

The equipment was tested in terms of the following main functions:

- washing function for the desorption of the pollutant;
- solid/liquid separation functions to transfer the pollutant to the water phase and leave a wet sand with a very low hydrocarbon content;
- liquid/liquid separation function to concentrate the pollutant in fluid form for subsequent treatment and recycling of wash water.

Contaminated sand is fed into the hopper by means of a shovel loader then transferred to a drum scrubber by a conveyer belt. Heated wash water (15-20°C to 50-60°C depending on degree of weathering) and cleaning agents are added. The sand/water/cleaning agent mixture is stirred and contacted for approximately 5 to 10 minutes then transferred onto a 5 mm grate to eliminate the bulky products such as gravel, stones and seaweed. The recovered sand is diluted with recycled wash water then pumped to the hydrocyclone. The oil-rich liquid phase leaving the overflow is carried by gravity into the settling tanks. The solid phase (washed sand) leaving in the underflow is transported on a vibrating belt, for maximum elimination of interstitial water, to a storage area. It is then returned to the site from which it was taken.

Two series of tests were carried out: one with 15 day weathered oil on sand (recent pollution) and a second with oil naturally weathered for several months on sand (old pollution). Washing quality was reported excellent in both cases (recent pollution - 90%, old pollution - 80% oil removal). A throughput of 18 metric tons of washed sand was achieved. Three types of cleaning agents were tested containing varying amounts of ionic/non-ionic surfactants in aromatic/non-aromatic petroleum cuts. It was found that in the case of unweathered sand/oil mixture, the addition of a surfactant did not improve washing efficiency. Weathered sand was more difficult to clean, requiring a washing temperature of 40°C. The unweathered sand was washed at 30°C. A relatively small amount of makeup water was required, of the order of 5 to 6 m^3/hr. This system is transportable by highway and is easily assembled by means of flexible couplings.

The mobile plant, designed for washing polluted sands was put to use following the Amazzone spill on January 31, 1988. This incident involved about 1500 tons of a highly paraffinic medium fuel oil along 300 km of the coast of Brittany (Huet et al. 1989). Pebble beaches were polluted, which had been especially difficult to clean during previous spills. An attempt was therefore made to clean the pebbles using the mobile sand-washer plant. The plant prototype was very easily adapted to washing the pebbles. The plant worked smoothly with a load of 20 to 25 m^3/hr, using a petroleum solvent as a washing agent. A total of 1400 m^3 was cleaned in 10 days. In comparison to other potential oily pebble beach cleaning techniques, the plant prototype proved very effective (good cleaning and high throughput was achieved) and competitive (cheaper than quicklime treatment). This technique also offered the advantage of returning the cleaned pebbles to the beach, thus preserving the pebble bank's anti-erosion function.

Plant prototype modifications for pebble cleaning included:

- installation of a rinsing device at the exit end of the drum scrubber to rinse off the thin film of oil and cleaning products as the pebbles pass through the trommel;
- attachment of three fire hose nozzles to a bank at the output of the trommel

Results from this washing trial suggested that the use of the mobile sand-washing plant prototype for cleaning shingle/pebble beaches was entirely feasible. The prototype effectively cleaned a polluted pebble beach without requiring significant modifications to the existing plant.

There have been no new developments in the area of pebble/cobble washing by the CEDRE, IFP and LCPC (Bocard 1990).

Homer Gravel Washer

The "Homer Gravel Washer" was developed privately to wash oil contaminated gravel from the "Exxon Valdez" spill in Prince William Sound. The system consists of a cantilevered trough and oil/water separators and heaters. Oiled gravel is manually loaded into the trough. Hot water is added and the gravel manually agitated for 5 - 7 minutes. Once the agitation is completed, the water/oil is drained out one end of the trough by tipping, then the cleaned gravel is removed at the other end of the trough, again by tipping. The oily water is sent to a separator where the oil is removed and the water recycled and reheated.

Roughly 10 minutes of operational time per batch was required during tests with oiled gravel from Prince William Sound - a batch consisting of a 5 minute wash period plus cycling time for 10 bags of gravel, at an estimated 20 - 30 lbs per bag. During the test period, 60 bags of gravel were processed in 1½ hours. The 60 bags of gravel were estimated to be equivalent to 0.54 yd^3, giving a throughput rate of 0.36 yd^3/hr or 0.27 m^3/hr.

The oil removal effectiveness of this system was not quantitatively determined, however visual observations of the final product indicated very good results. The energy usage is likely to be high due to the large quantities of hot water used. Heli-portability is likely feasible in units. The weight of the gravel washer is unknown but assumed to be quite high due to the number of steel tanks.

Northwest Processing Inc. beach cleaning systems

The Northwest Processing Inc. is a hazardous waste recycling facility which converts dangerous waste product into resalable products. Some of the materials that the plant is designed to process include: mineral spirits/oil, gasoline/diesel blends, gasoline/water mixtures, refinery tank bottoms, waste lubricating oils/solids/water, etc. They have also developed cleaning systems applicable to oily beach clean-up capable of:

- removing tar/asphaltic material from large rocks, rock cliffs and shoal areas;
- removing mousse from above and below the water level;
- removing, treating and returning the cleaned saturated sand and gravel mixtures to the beaches.

The systems have optimum throughput rates of 40 to 800 yd^3/hr. Assuming a 50% reduction in efficiency and converting the cubic yard measurement to surface measurements 3" in depth, a small system would yield approximately 240 yd^2/hr. The largest system would cover roughly 4,800 yd^2/hr of oiled beach. These systems can be deployed from barges, skids, excavators or hoes. Heli-portability of such systems is unlikely (Marshbank 1990).

Oily Waste Wash Plant - A.J. Energy Inc.

An "Oily Waste Wash Plant" was proposed to the Alaskan government by A.J. Energy Inc. for consideration and possible application to the Exxon Valdez spill. A bench scale prototype of the plant was set-up but mechanical difficulties with one of the pumps prevented any actual testing. Lack of funding has halted further development of this idea and a full scale plant has, to date, not been built (Jorgensen 1990). (The U.S. Department of Energy was to provide the funding initially, however a study revealed the concept to be uneconomical.)

The plant is designed to handle a range of sediment sizes, from sand to cobble and large rocks. A basket arrangement with interchangeable screens of variable mesh size would permit the selective washing of debris and sediment. The system would make use of readily available materials (i.e., 35 yd^3 dumpsters). The system would be portable and come complete with its own generator and pumping unit.

Summary

Table 1 is a summary of the applicability of existing beach cleaning equipment surveyed during this study and as well as those investigated in the 1984 COOSRA study. Most research in the area of oily beach cleanup has dealt with the modification of existing beach cleanup equipment, normally used to pick up litter, debris or seaweed. Existing systems for washing recovered oily sand/pebbles/gravel are based mainly on the principle of immersion, whereby the soiled material is immersed in a water/cleaning agent solution, and mixed in a washing cylinder or drum. The oil is then floated to the surface and removed while the cleaned material is removed from the bottom of the vessel and further processed.

TABLE 1
Applicability of Existing Beach Cleaners †

Machine	Sand	Applicability to Target Shoreline Pebble or Gravel	Cobble	Air Deployment Capability	Propulsion System Requirement	General Remarks
Oily Beach Cleaner	Yes surface clean only	Possibly small size coarse sizes unknown	No	Possibly wt unknown	Large FEL	Roller 8' wide; Bagger system powered by front-end loader (fel) hydraulics
Beach Maintenance Cleaner	Yes surface clean only	Possibly small size coarse sizes unknown	No	Yes	Pulled behind a small truck or tractor	Truck to straddle the line of pollution. Vehicles will mix sediment and oil on wide polluted areas.
Beemer Beach Cleaner	Yes (to 10 cm depths)	No	No	Possibly wt unknown	25 HP tractor (min) recommended	A few 25 HP tractors weighing under cm depths)High Flotation Tires 900 kg are available.
Comar - Mobile Surface Cleaner	Yes surface only	Possibly small sizes surface only	Mfr. claims useable on surface only	Yes in three components	Small 4 WD tractor	Recovery performance on coarse & porous beach sediments is questionable since slurries created slurries created in front of the surface cleaner would likely penetrate the surface. Operation on rough terrain is also questionable because of the small dia. solid mount wheels and low ground clearance of the surface cleaner.
Vikovac & Norvac	Yes surface only	Yes surface only	Yes surface only	Yes	N/A	Mobility may be limited on stretches of coarse sediment beach. The Norvac Power Pack could be fitted with larger dia. wheels, easy and timely movement to various locations may be limited because of the component nature of the systems and associated hoses.
Selective Drum (Cedre)	Yes surface only	Possibly small sizes	No	Possibly in sections, wt unknown	Tractor 40 HP min. heli-portability	40 HP tractors are over the limit for heli-portability
Reiba Uma 150 (Cedre Modified)	Yes to depth of 10 cm	No	No	Wt unknown	Tractor Powered HP unknown	May require considerable tractive effort from the tractor because of the soil cutting function. The tractor also powers the mechanical systems so the HP may be over the limit for heli-portability.
Modified Denver Rake Classifier	Yes	Yes	?	No	N/A	Very Complex
Modified Hardy Dadmore Submerged Screw Washer	Yes	Yes	?	No	N/A	Very complex.
Mobile System for Cleaning Oil Contaminated Beach	Yes	No	No	No		
Froth-Flotation Beach Cleaner	Yes	No	No	No		
Mobile Plant Prototype (CEDRE)	Yes	Yes with modification	?	Possibly in sections, wt unknown		
Homer Gravel Washer	Yes	Yes	Yes	Likely, in units		
Northwest Processing Mobile System	Yes	Yes	Yes	No	Mobile Power Barge	

† S.L. Ross, 1985

PROTOTYPE DESIGN

Design Criteria

A thorough investigation of state-of-the-art beach cleaning equipment revealed that a mechanical cleaning system was required for use on the following target shorelines:

- inaccessible mixed sediment beaches;
- cobble beaches; and
- boulder beaches.

In view of the above applications, the following criteria were set for the prototype design:

Feed Material Size:	Small sediment (slightly larger than sand grains) to 25-30 cm cobble.
Simplicity:	Materials of construction should be readily available; the unit can be easily assembled on-site.
Mechanical reliability:	Drive and support systems to be of common manufacture.
Heli-portability:	The system is composed of easily assembled components weighing under 900 kg (for Bell Jet-ranger transport); components have external dimensions of less than 200 cm wide x 270 cm high (for C 130 Hercules transport).
Throughput:	20 tonnes/hr, equivalent to approximately 100 man hours of manual sediment removal.
Manual Loading:	The system is to be manually loaded with shovels, buckets, etc.
Power Requirements:	Small diesel or AC electric motors.
Washwater/Solvent:	Variable pressure/flowrate/temperature capability.
Recycling/Oil Separation:	Washwater can be recycled or transferred elsewhere as required. Oil separated with an API-type separator.

Bench-scale Test

Prior to designing and building the full-scale prototype, the prototype bench-scale rock washer (S.L. Ross 1984) was refurbished in order to qualitatively determine its ability to remove Bunker "C" oil from cobbles. Tests with gravel and a range of oil types (other than Bunker C) had already been performed for the COOSRA study in 1984.

Methodology and Test Matrix

The bench-scale rock washer was configured as follows:

drum porosity:	low (as per S.L. Ross 1984)
rotational speed:	3 rpm
spray nozzle:	Spraying Systems "V-jet" 4005
Water pressure/flow:	400 psi = 0.09 L/s 750 psi = 0.11 L/s
Water temperature:	10°C and 40°C
Spray angle:	30° left (as per S.L. Ross 1984)

The cobbles purchased for the tests averaged from 200-250 mm in size and weighed approximately 10 kg each. For these tests 7 cobbles, with a total weight of 75 kg were loaded into the washer and then coated with 0.75 kg of Bunker "C", for an initial oil loading of 1% by weight. The drum was then rotated for 30 seconds to 1 minute until the cobbles were thoroughly covered with oil. At this point the spray was turned on and the test begun.

Post-cleaning samples of the cobbles were not taken because the Bunker "C" removed from the cobbles coated the inside surface of the drum and once the drum was stopped, dripped back onto the rocks. Cleaning efficiency was visually estimated.

The following test matrix was completed:

3 wash times (1, 3 and 5 minutes) x 2 water pressures (400 and 750 psi)
x 2 water temperatures (10°C and 43°C).

Observations

In general, the size of rock tested was the maximum for the device: two cobbles tended to stack themselves against the side of the rotating drum and were carried high up the side before falling; the impact loads on the drum were high; and three times individual rocks fell out of the prototype.

The washing process for cobbles is one of the spray flushing oil off the rocks, rather than a self-abrading action as noted in previous tests with gravel; as such slower rotational speeds and higher pressure sprays (400 psi) were most effective.

At a spray pressure of 750 psi with 10°C water the rocks were not clean after 1 minute, were noticeably cleaner after a 3 minute wash and most of the oil (except a few coin-sized patches) had been removed after a 5 minute wash time. Similar results were obtained with a 400 psi spray.

With 43°C hot water significant improvements in cleaning were apparent: after a 3 minute wash time the rocks were as clean as they had been after a 5 minute wash with cold water; after a 5 minute wash time with hot water the rocks were virtually spotless.

It was apparent that for the removal of Bunker "C" it would be necessary to use a much larger hole size and greater porosity for the perforated metal than was tested with the bench scale prototype (about 1 mm holes spaced 5 mm apart). The Bunker "C" removed from the cobbles had difficulty passing through the walls of the drum of the prototype.

Prototype Design

The prototype design was based on simplifying the COOSRA design by deleting movability criteria and feed and output material moving systems. The basic components of the proposed system were a 3 m long x 0.9 m diameter drum with internal auger flights and two perforated metal/screening sections for water/oil/fines removal.

The drum was constructed of standard (1.6 mm thick) corrugated culvert. Internal auger flights (11 ga. steel) were placed at 45 cm intervals along the length of the drum to increase the sediment residence time. Angle iron (1"x1"x1/8") was tack welded between auger flights for reinforcement and to increase tumbling. One cm holes were drilled every 10 cm over five corrugations in two sections of the drum to allow for water/oil/fines removal.

Five Vee-jet nozzles, mounted along the length of a 3/8" SCH80 pipe inside the drum, were used to spray water onto the sediment. Wash water was pumped with a Hypro piston pump, capable of delivering 7.35 gpm @ 400 psi. Recycled wash water passed through a visual liquid strainer to remove fines before entering the pump.

The drive mechanism for the prototype consisted of a 4.0-7.5 hp Lister Petter diesel engine and a series of gear reducers, chains and pulleys. A 10:1 reduction from the engine, which operates at 1500-3000 rpm, was achieved using a chain drive. From this point a double vee belt pulley powered both the water pump and the mill belt pulley used to rotate the drum. The mill belt was placed around the outside perimeter of the entrance to the drum.

The support structure for the rock washer was built from 3" standard C-shaped channel. The frame consisted of two identical welded sections, bolt connected at two points on the base between the two triangular sections (shown in Figure 8). This enabled the frame to be disassembled into components having dimensions which met the heli-portability criteria.

The drum rotated on and was supported by eight neoprene casters (6" dia.) each with a capacity of 500 lbs (227 kg). Angle iron bent around the outside perimeter of the drum, formed a track in which the casters could ride.

The design rotational speed of the drum was 6 rpm, which, with an auger pitch of 45 cm, gave a residence time of roughly 60 seconds. Wash water (cold) could be sprayed at 35 kPa from 5 internally mounted spray nozzles at a total flowrate of 30 L/min (1.8 m^3/hr). For the prototype, provision were made for hot-water spray and for the first nozzle to spray diesel fuel (for softening/loosening of baked-on oil). The design throughput of the device was 20 tonnes/hr (10 m^3/hr) with a holdup of 500 kg of sediment.

The washwater/oil/fines mixture exits the drum at two perforated sections in the drum and collects in a simple separator tray placed beneath the device. The fines settle in the first section of the tray while oil and water move to the centre to separate; oil is skimmed off and the water recycled. Wiper blades could be included against the outside of the drum to assist in removing viscous oils from the drum surface if required.

On-site modifications included the following:

- a plywood trough lined with plastic was built and placed at the entrance of the rock washer in order to facilitate manual loading;
- angled eaves troughing was used to collect water leaving the output end of the rock washer and return it to the separator.

TEST SITE, MATERIALS AND EQUIPMENT

Test Site

The trials were conducted near Ottawa, Ontario. Photographs of the test set-up are shown in Figure 3. The test site had the following facilities:

- water @ 30 L/min minimum (6.6 gal/min) with consumption to a maximum of 2700 L/day
- water @ 40^{oC} from a domestic hot water tank
- accessible by truck
- plastic lined sand/gravel pad 4 m x 2 m x 20 cm (1.6 m^3) on level ground

Test Oils

Two test oils were used: an Ontario light crude oil and Bunker "A". Crude oil was used in three different states: fresh, weathered and emulsified. Crude oil termed "fresh crude" in the test matrix, was lightly weathered by air sparging, to at least 10% evaporative loss. The weathered oil was prepared by spraying fresh crude on the test sediment and allowing it to weather naturally, outdoors for a period of at least two weeks. The "emulsified" oil was created by mixing 25% crude oil and 75% water in a drum using a paint mixer. As the emulsion obtained was unstable, some Bunker "A" (roughly 10%) was mixed with he crude. This stabilized the emulsion.

The following table lists the initial properties of the oils used in this study.

TABLE 2
Initial Properties of Test Oils

Test Oil	Viscosity (m.Pas) @ 23.4°C	Density (kg/m^3) @ 21.8°C
"fresh" crude	10	834
emulsified crude #1	41	895
emulsified crude #2	--	967
Bunker A	96	920

Test Sediment

The rock washer was tested with three types of sediment: a coarse gravel ranging in size from 50 to 100 mm in diameter (denoted as 50 mm), large cobble ranging in size from 150 to 200 mm in diameter (denoted as 200 mm) and a mixture consisting of cobble, gravel and sand in a 45:45:10 ratio by weight. Sand was added to the mixed sediment to test the rock washer's effectiveness in removing fines from the coarser sediment. The test sediment was obtained from a local quarry which provided the above size ranges.

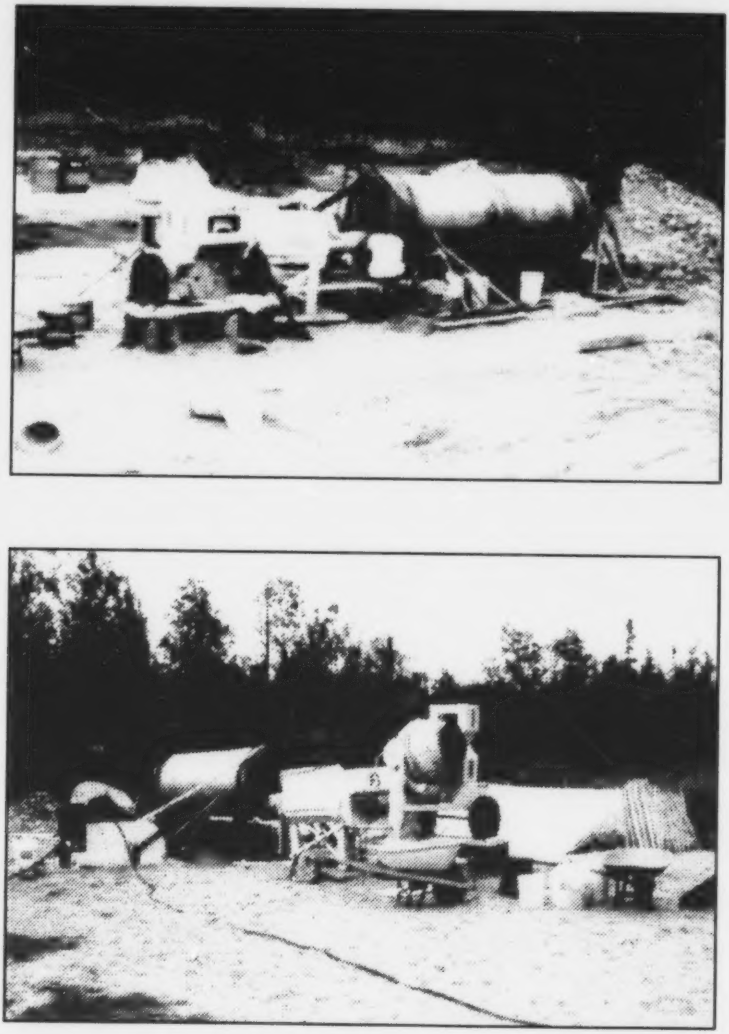


Figure 3: Rockwasher test site

Oil loadings in the 0.25 to 2% by weight range were used (0.5 to 4% by volume). Smaller oil loadings were applied to the larger sediment because of its reduced surface area to volume ratio.

The sediment was prepared for testing as follows:

- runs with Bunker A, fresh and emulsified crude: the sediment was prepared by mixing known weights of sediment and oil in a 6 ft^3 portable cement mixer until all the sediment was thoroughly coated with oil;
- runs with weathered crude: three weeks prior to the tests, six plots were prepared for weathering oiled sediment. Each plot consisted of a 2 m^2 enclosure constructed of 2" x 6" lumber (on side) lined with 6 mil plastic sheet. In two of these, 1 m^3 of coarse gravel was placed; in another two, 0.5 m^3 of large cobbles was placed and in the last two, a 45:45:10 wt. mixture of cobble, gravel and sand was placed. Appropriate amounts of "fresh" crude oil were sprayed onto each plot using a "backpack" sprayer.

TABLE 3
Test Matrix for Rockwasher Program

Rock Size Size (mm)	Oil Type	Oil Loading (wt %)
50	"fresh" crude	2 0.5
	weathered crude	2 0.5
	emulsified crude	2 0.5
	Bunker "A"	1 0.5
200	"fresh" crude	1 0.25
	weathered crude	1 0.25
	emulsified crude	1 0.5
	Bunker "A"	0.5 0.5
mixture (45 wt% each of 50 and 200 and 10 wt% of 0.5 mm coarse sand)	"fresh" crude	1 0.25
	weathered crude	2 0.25
	emulsified crude	1 1
	Bunker "A"	2 0.25

PROCEDURES

Test Methodology

The following were the procedures used for each test.

1. The sediment/oil combination was prepared (using either the 6 ft^3 portable concrete mixer for the Bunker A, and emulsified crude runs or spraying/coating the oil for the weathered crude runs) and placed in the lined trough at the feed end of the rock washer.
2. The rock washer was started and sprays turned on.
3. The stone was shovelled or manually pushed into the feed end of the washer at a steady rate. Over the first minute, or longer if necessary, of the test the washer speed and sprays were adjusted to give optimum cleaning; the remainder of the test was run at the selected conditions. If the oil type warranted it (i.e., Bunker "A") hot water was used for the spray.
4. On completion of the test, the processed stone was prepared for the next test.

Sampling and Analysis

For each test, samples were taken to monitor the following parameters:

Prior to Test
1) viscosity and density of oil
2) concentration of oil in feed determined by weighing total oil applied to a known weight of sediment

During Steady-State Operation
3) oil content in recycled washwater
4) concentration of oil in output (1 sample per run)
5) emulsion water content in recovered oil.

The laboratory analysis of the collected samples was performed by EED at the River Road laboratories using the following methods:

1) Viscosity:
   - Bohlin Visco 88 rotational viscometer

2) Density:
   - Anton - Pear DMA45 digital density meter as per ASTM D4052-86

3) Concentration of oil in output:
   - three methods were used in this determination.

   i) Processed sediment samples were weighed, then washed for approximately five minutes in a tared 3000 ml beaker with dichloromethane as the solvent. The cleaned rocks were removed from the wash bath and allowed to dry. The sampling bag was then washed in the solvent bath to remove any remaining oil. The cleaned samples were reweighed and the weight of oil on the sediment determined.

ii) Oil remaining on the sediment was also determined by measuring the amount of oil removed from the sediment during the solvent wash in method i). The solvent in the tared beaker was allowed to evaporate and the beaker containing the remaining oil was reweighed and the oil mass determined. This method was used to compensate for any silty material removed during the solvent wash. Weights obtained from both methods were averaged and compared against the sample weight to gain a weight percentage of oil present on the processed sediment.

iii) The sediment and sampling bag were weighed and washed with about 250 ml of dichloromethane. The rinsing was collected and filtered using #1 Whatman paper. The filtered rinsing was evaporated to exactly 10 ml, initially with a rotovap, then finished off under a stream of N_2. The amount of oil (μg) in the 10 ml was determined using a U.V. spectrometer and calibration curves of known concentrations of oil in water.

4) Emulsion water content in recovered oil:
   - Metrohm 701 Karl Fisher automated titrator as per ASTM D4377-88.

5) Oil content in recycled washwater
   - Horiba OCMA-220 Oil Content Analyzer

Data Collection

For each test, during steady-state operations, the following was also measured:

- washer rotational speed (timed with stopwatch)
- washwater and/or diesel spray flowrates and pressures (timed flow and pressure gauge)
- sediment throughput rate
- sediment residence time

RESULTS AND DISCUSSION

The full-scale prototype rock washer, tested with gravel, cobble and mixed sediment showed promising results. The following parameters were monitored throughout the trials: oil in output, emulsion water in recovered oil, oil in recycled water, throughput rate and residence time. Visual and photographic observations of the test sediment were also made, at the beginning and at the end of each run.

Some changes to the original test program were made once on-site testing began. It was found that an oil loading of 2% exceeded the amount required to completely saturate the test sediment, and resulted in oil collecting in the bottom of the loading trough. An oil loading of 1% was therefore used, except in the case of the weathered oil. This oil was applied 2 to 3 weeks prior to testing, in two batches on separate days in order to allow the oil to dry onto the sediment. Most of the oil applied in this manner remained on the sediment, even at the higher oil loading. Several of the runs originally planned for testing were omitted. Some of the 0.25% oil loading runs were omitted if the same sediment with a high oil loading was successfully cleaned after one pass through the rock washer. It was assumed that if heavily oiled sediment could be successfully cleaned, lightly oiled sediment would be as well. A total of 19 runs were completed, as well as three reruns for sediment which was not satisfactorily cleaned the first time through the rock washer.

The rock washer's performance was evaluated quantitatively by determining the amount of oil remaining on the processed sediment and qualitatively by making visual observations of the test sediment before and after each run.

Quantitative Analysis

Oil in output, throughput rate and residence time have been plotted as a function of oil type and loading for each rock size tested (see Figures 4a to 4c). The oil content in the output sediment was determined by collecting sediment samples at the end of each run and analysing for remaining oil. Some difficulties were encountered with the laboratory analysis of these samples. Three different methods were used to determine the amount of oil remaining on the sediment after washing. Two gravimetric methods of analysis were used first which involved removing the oil from the sediment by solvent washing and weighing the samples before and after washing, as well as weighing the removed oil. However, the balance used in these determinations was not reliable, therefore results obtained had a large error (up to ± 20g). Also, this method did not account for the presence of silt on the sediment, which would have been removed to some unknown degree with the oil during the washing step. Because of the small oil-mass to sediment-mass ratio, even small amounts of silt removed from the sediment would significantly affect the results obtained. Silt removed with the oil would erroneously increase the percentage of oil in the output. These results are therefore not reliable and do not accurately represent the amount of oil remaining on the processed sediment. This is particularly evident in the following runs: i) 200 mm - emulsified crude - 0.25% oil; ii) 200 mm - Bunker A - 0.25% oil; and iii) mixture - weathered crude - 0.25% oil. The percent oil in output for these runs was found to be higher than the initial percent oil loading despite the fact that the visual observations clearly show the rock to be clean after passing through the rock washer.

In general, the numbers obtained for oil in output using the above methods were much higher than expected (0.1 - 0.9 wt %). Unfortunately, most of the samples were anlayzed using the above two methods. As these results are not reliable, they will not be further discussed. They have, however, been included in Figures 4a to 4c.

The remaining samples (those marked with an asterisk in Table 4) were analysed for oil using the third method. This method involved extracting the oil from the sediment and silt with a known volume of solvent, then determining the percent oil in the solvent by UV spectrometry. Percent oil on the sediment was thus determined independently of any silt removed from the rocks. As expected, these numbers (in the 0.00 to 0.02% range) are much lower than those obtained using the previous methods.

In order to discuss the overall performance of the rock washer as a function of sediment size and oil type, the visual observations will be used.

TABLE 4
Summary of rock washer test results

Rock Size (mm)	Oil Type	Oil Loading (%)	Oil in Output (%)	Emulsion Water (%)	Oil in Recycle H_2O (ppm)	Water Temperature (°C)	Throughput Rate (kg/sec)	ResidenceVisual TimeObservation (sec)of Output Cleanliness†
50	fresh crude	1	0.09	27	256	12		1
50	fresh crude	0.5	0.00*	73.61	216	12	3.4	720
50	weathered crude	2	0.42	10.0		43	4.5	760
50	weathered crude	0.5	0.25			12	3.9	620
50	emulsified crude	2	0.01*		388	12	3.7	691
50	Bunker A	1	0.02*	70.67		43	3.5	773
	2nd wash		0.00*			20	3.4	681
50	Bunker A	0.5	0.02*			43	3.5	753
	2nd wash		0.00*			20	3.4	681
200	fresh crude	1	0.16	79.25	48	12	3.7	601
200	weathered crude	1	0.36	0	57	43-12	4.2	750
200	weathered crude	0.25	0.52		57	12	4.4	740
200	emulsified crude	1	0.57		26	12	3.9	802
	2nd wash		0.15			43	4.4	730
200	emulsified crude	0.5	0.24			43	4.8	840
200	Bunker A	0.5	0.43			43	3.6	722
	2nd wash		0.90			43	3.6	661
mixture	fresh crude	1	0.35		107	12	3.0	741
mixture	fresh crude	0.25	0.26		107	12	3.8	670
mixture	weathered crude	2	0.67			12	3.7	700
mixture	weathered crude	0.25	0.70			12		0
mixture	emulsified crude	1	0.08			43	4.0	710
mixture	Bunker A	1	0.14	44.95		43	2.7	542

†0 - sediment completely clean
1 - sediment essentially clean but with a very light sheen of oil remaining
2 - light sheen and the occasional spot of oil remaining on sediment
3 - large spots of oil remaining on sediment - second washing required

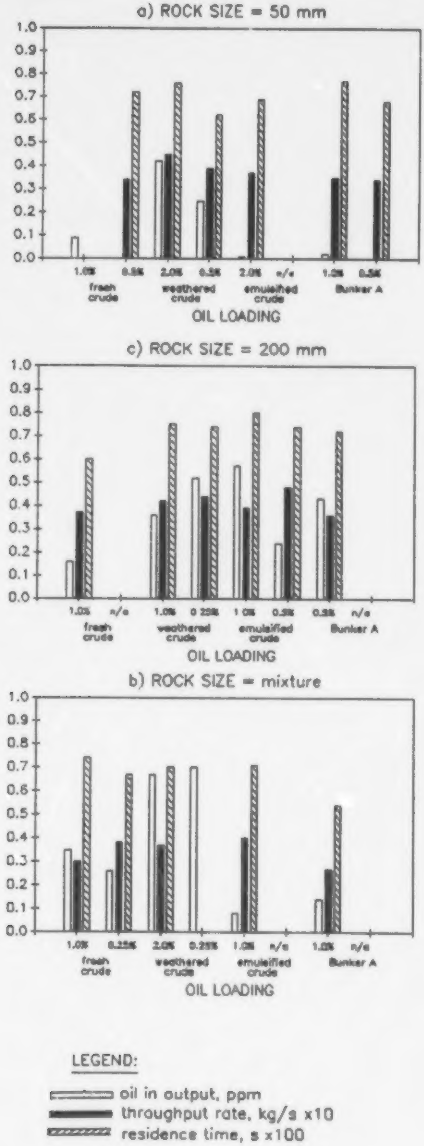


Figure 4: Test results as a function of rock size and oil type

Qualitative Analysis

A qualitative analysis of the rock washer's performance was carried out, by simple visual observation of the test sediment before and after each run. Photographs of the test beach sediment taken before and after passing through the rock washer were used in this analysis. Table 5 outlines the visual observations for each run performed. A scale rating used to describe the degree to which the sediment was cleaned was set up as follows:

0 -sediment completely clean
1 -sediment essentially clean but with a very light sheen of oil remaining
2 -light sheen and the occasional spot of oil remaining on sediment
3 -large spots of oil remaining on sediment - second washing required

This scale rating appears in Table 5. The results indicate that for approximately 50% of the runs, the sediment was completely cleaned, and that for roughly 70% of the runs, the sediment was either completely cleaned or only a light sheen of oil remained after washing. These runs consisted mainly of sediment oiled with fresh or weathered crude. All sediment/weathered crude combinations were completely clean after a single pass through the rock washer. After processing, sediment oiled with fresh crude, at the lower initial oil loadings (0.25-0.5%) was completely cleaned, while a very light sheen of oil remained on the sediment oiled with fresh crude at the higher oil loading of 1%.

These observations indicate that the ease with which the oil types tested are removed from beach sediment is as follows, in order of increasing difficulty: weathered crude, "fresh" crude, emulsified crude and Bunker A. Crude oil, in its various states, was much easier to remove than Bunker A. As expected, Bunker A proved to be the most difficult oil to wash from the beach sediment tested, requiring the use of hot water and/or a second pass through the rock washer.

It is difficult to determine from the visual results if the cleaning efficiency varied with sediment type. Previous tests indicated large cobble was cleaned by the spray flushing oil off the rock, while the washing process for gravel and smaller sediment was enhanced by the self-abrading action of the sediment. Although a great difference in cleaning efficiency was not observed among the sediment types tested, the mixed sediment did seem to be slightly easier to clean than the cobble and gravel.

While the quantitative analysis of oil in the output determined by the gravimetric method was unreliable, the results obtained by UV spectrometry were consistent with the visual observations made of the processed sediment. Oil in the output for gravel and Bunker A (1% and 0.5% loadings) was 0.02%, the highest percentage measured by UV spectrometry. Visually, some large oils spots remained on the sediment and a second wash was required (which corresponds to a "3" on the visual rating scale). Processed sediment for runs where the oil in the output was determined to be 0.01% or less by UV spectrometry, were also observed to be either completely cleaned or to be covered with a light sheen of oil (visual rating scale of "0" and "1").

Although, the above comparisons would suggest that visual observations offer a fairly reliable means of evaluating the rock washer's cleaning efficiency, they may be somewhat subjective.

TABLE 5
Summary of Visual Observations of Processed Sediment

Completely Clean	Light Sheen	Light Sheen with Small Spots	Many Large Spots 2nd Wash Required
Fresh crude-50 mm-0.5%	Fresh crude-50 mm-1%	Emulsified-200 mm-1%	Bunker A-50 mm-1%*
Fresh crude-mixed-0.25%	Fresh crude-200 mm-1%	Bunker A-200 mm-0.5%*	Bunker A-50 mm-0.5%*
Weathered-50 mm-2%*	Fresh crude-mixed-1%	Bunker A-mixed-1%*	
Weathered-50 mm-0.5%	Emulsified-50 mm-2%		
Weathered-200 mm-1%*	Bunker A-50 mm-1%†		
Weathered-200 mm-.25%	Bunker A-50 mm-0.5%†		
Weathered-mixed-2%	Bunker A-200 mm-0.5%*†		
Weathered-mixed-0.25%			
Emulsified-200 mm-1%*†			
Emulsified-200 mm-0.5%*			
Emulsified-mixed-1%			

* = hot water wash
† = second wash

Operating Conditions

It was found that cold water washing with a water pressure of 700 kPa was sufficient for all oil/sediment combinations except those involving Bunker A. Large oil spots remained on the sediment oiled with Bunker A when washed with cold water, after one pass through the rock washer. The rocks were much cleaner after a second pass.

The drum rotation speed was maintained at approximately 5 to 6 rpm during all runs. It had been planned to vary the rpm, however it was not possible to vary the diesel engine speed in such a way that a change in drum rotation was noticed. A drum rotation speed of 5-6 rpm gave a theoretical residence time of 60 to 80 seconds, which was in fact the range obtained during the trials (see Table 3). This was sufficient for most runs, with the exception of those involving Bunker A. Longer residence times (lower rpm) combined with higher wash water pressures may have improved the cleaning efficiency in the case of Bunker A contaminated sediment.

The rock washer was manually loaded by two or three people using shovels and rakes. Two people were also required at the output to shovel cleaned sediment away from the end of the drum. Throughput rates varied from 2.7 to 4.8 kg/sec (10 - 17 tonnes/hr). The average throughput rates for cobble, gravel and mixed sediment were 4.0 kg/sec (14.4 tonnes/hr), 3.7 kg/sec (13.3 tonnes/hr) and 3.4 kg/sec (12.2 tonnes/hr) respectively.

Ear protection is recommended during the operation of this equipment, however due to the limited scope of this project, the question of safety has not been fully addressed. Safety should be further studied and the prototype redesigned to include safety features such as a belt guard and protecton form pinch points.

Separator Efficiency

The purpose of the separator tray was to collect the wash water/oil/fines mixture exiting the drum and to separate the components of the mixture in such a way that oil could be skimmed off and water recycled back to the rock washer. Oil content in the recycle was water was determined in order to assess the separator efficiency. Separator water was sampled from the spray nozzles as it was recycled back to the rock washer. Samples were taken during several of the fresh, weathered and emulsified crude runs. No samples were taken for the Bunker A runs since fresh hot water was used to wash the sediment and was therefore not recycled. The recycle water data obtained are not accurate measures of the oil concentration in the separator water, but rather of the quality of water recycled and used to spray the oily sediment. The separator was not emptied between runs, therefore oil from previous runs is also likely to be present in the water as well as oil removed during a current run. The data showns that this separator was effective in separating oil from water. Water recycled back to the rock washer contained oil in the 20-400 ppm range. The separator was observed to effectivel collected fines and sand washed from the sediment. This observation also indicates that the hole size of 1 cm used in the two perforated sections of the drum was adequate.

CONCLUSIONS

This rock washer trial was successful in that the prototype tested effectively cleaned oily beach sediment. The following conclusions have been made.

1. Average throughput rates of 4.0 kg/sec (14.4 tonnes/hr) for cobble, 3.7 kg/sec (13.3 tonnes/hr) for gravel and 3.4 kg/sec (12.2 tonnes/hr) for mixed sediment were achieved.

2. The ease with which the oil types tested could be removed from beach sediment was, in order of increasing difficulty: weathered crude, "fresh" crude, emulsified crude and Bunker A.

3. Cold water spray at a pressure of 700 kPa was sufficient to wash all oil types, with the exception of Bunker A, from the test beach sediment. Hot water was required for the Bunker A, as well as a second wash in most cases.

4. The hole size of 1 cm in the two perforated sections of the drum was adequate for the removal of washwater/oil/fines mixture. Wiper blades against the outside of the drum (not included in this prototype) to assist in removing viscous oils from the drum surface, may have been useful, but were not required for the oil/sediment combinations tested.

5. The API-type separator used to collect the washwater/oil/fines mixture leaving the rock washer at the perforated sections was effective in separating this mixture. Oil and emulsified oil separated from the water and floated to the surface, while fines collected at the bottom of the separator. The water, which was recycled and used for washing the test sediment contained between 26 and 256 ppm oil in water.

6. Overall, the materials and equipment chosen for this rock washer prototype were found to be adequately suited to this purpose.

RECOMMENDATIONS

1. This rock washer prototype is not mobile and is therefore limited in its applicability to actual beach cleanup operations. However, knowing that the concept tested is effective, construction of a mobile cobble washing device similar to the prototype tested, deserves serious consideration. One possibility would be to have the rock washer mounted on independent wheels, towed by a tractor and powered by the tractor's PTO.

2. Possible improvements to this prototype might include the following:
   i) using diesel at the first spray nozzle to soften oil particularly in the case of sediment oiled with Bunker;
   ii) decreasing the drum RPM's when washing Bunker from sediment - a longer wash cycle might improve output oil concentrations;
   iii) increasing the water pressure - although the laboratory tests indicated this factor had only a small effect on the results obtained.

ACKNOWLEDGEMENTS

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ARABIAN GULF OIL SPILL: SHORELINE SURVEYS AND CLEANUP GUIDELINES FOR BAHRAIN AND QATAR

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ABSTRACT

Aerial videotape surveys were conducted for the coasts of Bahrain and Qatar following the Gulf War oil spills to generate a data base from which maps of the shoreline character could be developed. These maps, in conjunction with shoreline protection and cleanup guidelines, were prepared as part of a Canadian technical assistance program for input into contingency planning and operational support following the spills.

INTRODUCTION

Shortly after the Gulf War oil spills occurred, Canada initiated a technical assistance program for the two Gulf states of Bahrain and Qatar. In the first phase of the program, a six-person assessment team was sent to the region. Their mission was to (a) assess the oil spill preparedness and response capabilities of Bahrain and Qatar for protection and cleanup of their resources and facilities; (b) determine what was needed from Canada in terms of equipment, material and expertise; (c) determine contributions from nations; and (d) assess the framework for international cooperation.

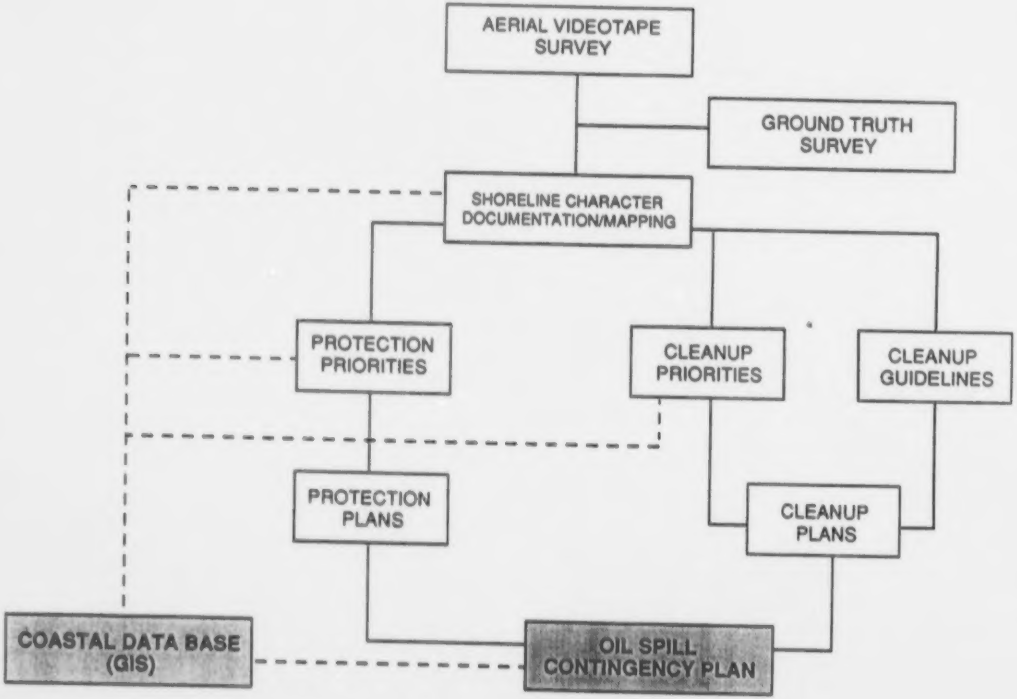
The second phase of support involved specific responses at both bilateral and multilateral levels, based on the report of the assessment team. Canadian expertise and support was recommended for the task of surveying and documenting the bio-physical characteristics of threatened shorelines; and in recommending shoreline protection and cleanup guidelines appropriate to the various types of coast. Since the oil had not yet reached the coasts of Bahrain and Qatar, the information would be useful for both contingency planning and operational support. Acting on these recommendations, Environment Canada immediately planned and implemented a field program which was conducted between 20 February and 1 March.

An important facet of the field program, which involved aerial reconnaissance surveys, was that the work was conducted in a war zone and coincided with the ground war to liberate Kuwait. The fact that the project was completed successfully as planned within a short time period, with so many complicating external and internal pressures, is a tribute to the cooperation and commitment of the military and civilian personnel of the two states and Canada who supported the activities.

PROGRAM OUTLINE

Planning for shoreline protection and shoreline cleanup as part of a spill response program involves a knowledge and understanding of the coastal environment and of the extent and character of the oil. The approach to collection of the necessary shoreline and oiling information varies depending upon whether the planning is carried out (1) before a spill occurs or (2) after the coast has been oiled. The two approaches are outlined in Figures 1 and 2.

This project was a Pre-Spill Survey in which an aerial videotape survey was conducted to provide data on shoreline conditions, which could then be used to develop detailed protection and cleanup priorities and plans as part of local Oil Spill Contingency Plans.



PRE - SPILL SURVEY

AERIAL VIDEOTAPE SURVEY
GROUND TRUTH SURVEY
SHORELINE CHARACTER DOCUMENTATION/MAPPING
PROTECTION PRIORITIES
CLEANUP PRIORITIES
CLEANUP GUIDELINES
PROTECTION PLANS
CLEANUP PLANS
COASTAL DATA BASE (GIS)
OIL SPILL CONTINGENCY PLAN

Figure 1. Pre-Spill Approach

The information obtained on the primary shorezone features was used to develop a set of shoreline cleanup recommendations. These recommendations were prepared to include three different types of oil spills:

- light products
- fresh crude and medium products
- weathered crude and heavy products

in order that the recommendations may have a broader application than the present oil spill threat. The oil spilled in January and February in the northern Arabian Gulf will have weathered considerably should it reach the coasts of Bahrain. The guidelines that have been developed for the weathered crude/heavy product category apply best to the present (spring 1991) situation.

The field effort focussed on a low-altitude aerial videotape survey to generate a data set on the physical shore-zone character (Owens and Reimer, 1991). This data was mapped at a scale of 1:50,000 so that it could be used subsequently as part of a coastal data base (Geographical Information System). Time permitted only a few site visits to obtain ground-truth for the aerial survey.

VIDEOTAPE SURVEY

The aerial colour videotape survey of Bahrain was conducted on 23 February, 1991, using a Bell 212 helicopter of the Bahrain Defence Force. Approximately 150 km of coast were flown at low altitude (30 to 75 m) and the coverage of the shore zone was complete with the following exceptions:

- the west coast between Az Zallaq and the Causeway
- some short sections on the northwest coast: Khawr Al Kabb, Khawr Al Qulayah, and Dawhat Al Muharraq
- the Hawar Islands.

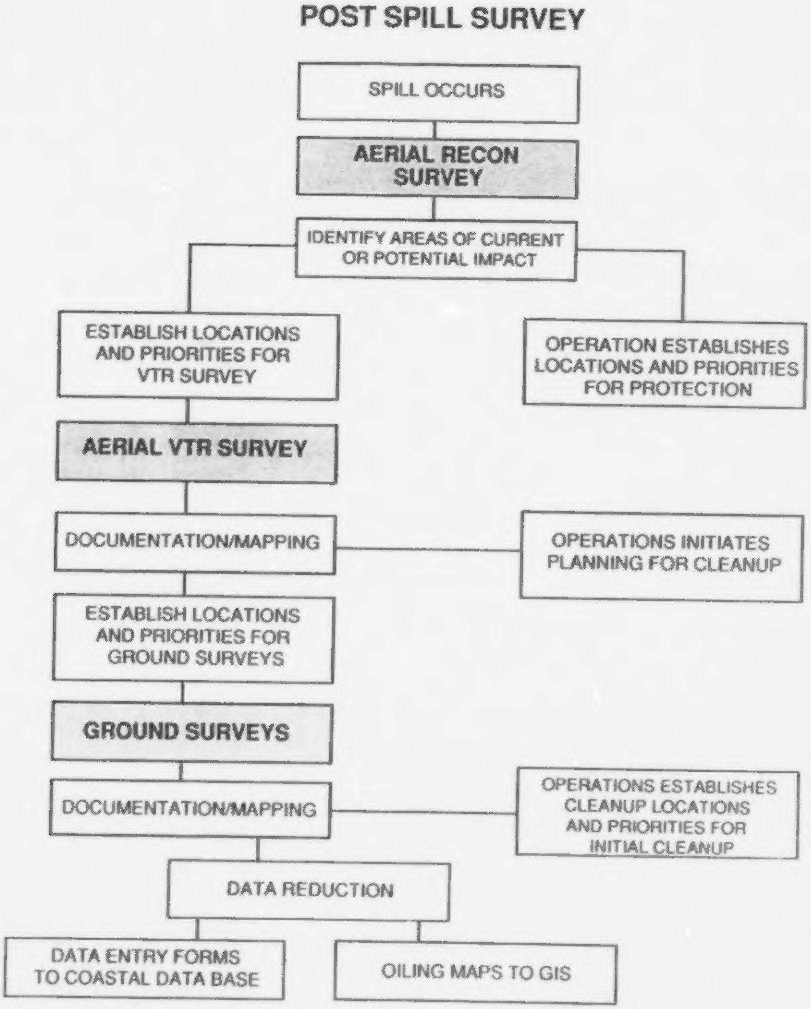

POST SPILL SURVEY
SPILL OCCURS
AERIAL RECON SURVEY
IDENTIFY AREAS OF CURRENT OR POTENTIAL IMPACT
ESTABLISH LOCATIONS AND PRIORITIES FOR VTR SURVEY
OPERATION ESTABLISHES LOCATIONS AND PRIORITIES FOR PROTECTION
AERIAL VTR SURVEY
DOCUMENTATION/MAPPING
OPERATIONS INITIATES PLANNING FOR CLEANUP
ESTABLISH LOCATIONS AND PRIORITIES FOR GROUND SURVEYS
GROUND SURVEYS
DOCUMENTATION/MAPPING
OPERATIONS ESTABLISHES CLEANUP LOCATIONS AND PRIORITIES FOR INITIAL CLEANUP
DATA REDUCTION
DATA ENTRY FORMS TO COASTAL DATA BASE
OILING MAPS TO GIS

Figure 2. Post-Spill Approach

The aerial survey involved approximately 3 hours of actual taping using a HI-8mm recorder and approximately 250 still colour photographic 35-mm slides were taken during the flight. In addition, ground sites visits were made to 16 locations on 21-22 February, 1991.

The aerial survey of Qatar was conducted on 25-26 February, 1991, using Sea King helicopters of the Qatar Emiri Air Force. Approximately 500 km of coast were flown at low altitude (30 to 75 m) and the coverage of the shore zone was complete with the following exceptions:

- the southwest coast, south of 25 deg. N.
- the Hawar Islands
- a few, very short, restricted sections on the each coast (for example, some military installations and the Emir's palace in Doha).

The aerial survey involved approximately 4 hours of actual taping using a HI-8mm recorder and approximately 500 still colour photographic 35-mm slides were taken during the flights. In addition, ground sites visits were made to 10 locations on 26 February, 1991.

SHOREZONE MAPPING

The data recorded on the video and audio channels from the aerial survey have been interpreted and shore-zone types have been plotted by hand on a set of 1:50,000 scale topographic maps. A list of the shore-zone types defined for this study and the abbreviations used to code the maps is given in Table 1.

TABLE 1. SUMMARY OF SHORE-ZONE TYPES AND CODES USED FOR 1:50,000 COASTAL MAPS

1 - SAND (S)		
1a	sand beach	(SB)
1b	sand barrier beach	(SBB)
1c	sand shorezone	(SS)
1d	mangrove	(SM)
2 - BEACHROCK (BC)		
3 - BEDROCK (BD)		
4 - MANMADE (M)		
4a	riprap	(MRR)
4b	rubble	(MRU)
4c	seawall	(MSW)
5 - NEARSHORE/TIDAL FLATS		
	- sand flats	(s -)
	- sand/mud flats	(sm-)
	- bedrock terrace	(bd -)
	- beachrock flats	(bc -)
	- narrow	(- n)
	- medium	(- m)
	- wide	(- w)

GUIDELINES FOR SHORELINE RESPONSE

The coastal zone is a complex environment in which there are a variety of landforms and sediment types. Only a detailed shoreline contingency plan can provide sufficient detail for every different section of the coast. However, the guidelines developed as part of this project present recommendations that can be applied at a general level for the major categories of shoreline types that occur within the region. Guidelines have been prepared for each of the eleven shoreline types listed in Table 1.

RESPONSE GUIDELINES FOR PREDOMINANT SHORELINE TYPES

The cleanup methods that are appropriate for the most common shoreline types found in the area, in terms of operational efficiency and of environmental acceptability, have been outlined in the study reports submitted to each of the respective Environmental Protection agencies in Bahrain and Qatar. A graphic summary that relates these methods for each of (a) the shoreline types, and (b) the three oil categories used in this analysis is given as a series of figures, of which Figure 3 is an example for high-viscosity oils.

REFERENCE

Owens, E.H. and Reimer, P.D., 1991. Aerial Videotape Shoreline Surveys for Oil Spill Reconnaissance, Documentation and Mapping; Proceedings of the International Oil Spill Conference, San Diego, CA, 4-7 March, American Petroleum Institute, Washington, D.C., Pub. No. 4529, pages 601-605.

Qatar Cleanup Guidelines for Weathered Crude or Heavy Product Spills (High Viscosity Oils)

Shoreline Type	Code	Manual Removal	Mechanical Removal	Pumps–Vacuum	Vegetation Cropping	High–Pressure Wash	Low–Pressure Wash	Dispersants
Sand Beach	SB	■	■	▒	NA	▨	▒	NA
Sand Barrier - Lagoon Beach	SBB	■	■	▒	NA	▨	▒	NA
Sand Shore	SS	■	■	▒	NA	▨	▒	NA
Mangrove	SM	▒	▨	▒	□	▨	▒	NA
Beachrock	BC	▒	NA	▒	NA	▒	■	NA
Bedrock	BD	▒	NA	▒	NA	▒	■	NA
Riprap	MRR	▒	NA	NA	NA	▒	■	NA
Rubble	MRM	▒	▒	NA	NA	▒	▒	NA
Seawall	MSW	NA	NA	NA	NA	▒	■	NA
Sand Flats	/S	■	□	□	NA	▨	□	NA
Sand-Mud Flats	/SM	□	□	□	NA	▨	□	NA

Key:

■	Preferred
▒	Optional
□	Not Advisable
▨	Avoid
NA	Not Applicable

Figure 3. Example of Shoreline Cleanup Guideline Matrix

WORKING WITH AND REGULATING THE OIL INDUSTRY IN PRINCE WILLIAM SOUND

A NEW CONCEPT OF PUBLIC INVOLVEMENT

PRESENTATION OF
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How much better prepared are we to prevent an oil spill or to respond in the event of a spill with increased citizen involvement? Is the oil industry better regulated in Prince William Sound since an increased interest and oversight by the public? We have learned some valuable lessons regarding citizen involvement and spill response prevention and preparedness as a result of the EXXON VALDEZ disaster. We are in the process of learning about citizen involvement from the standpoint of increased oversight and questioning of the State and Federal role in regulation of the oil industry. None of the lessons we have been learning have come easy.

OVERVIEW

One important lesson that has taken hold and is bearing fruit is the realization that much more progress towards achieving positive industry contingency planning and oversight results are gained through a spirit of working together with citizen groups, the industry and the Coast Guard. We have learned that in order to have a spill response with an adequate efficiency, you need to have a well thought out attack strategy with the equipment on-hand, in the region of operation, for an almost immediate response so that you have the best opportunity to attain your planning standard goal. You must have the capability to bring equipment into the spill area in order to maintain a sustained response and/or to handle the response to the realistic maximum oil discharge. We also learned that contingency planning must include adequate initial and continued training and drills. We are learning that oversight programs must be designed to build public trust that industry is properly regulated. And most importantly, there needs to be some mechanism to counter the tendency for industry, State and Federal governments and the public to develop complacency.

I started reviewing the Prince William Sound (PWS) contingency plan in May of 1990 and I've been in the middle of the Alyeska and oil shipping companies "oversight controversy" since it re-surfaced in February of this year. Considerable progress has been made working with the PWS Regional Citizens Advisory Council (RCAC), the USCG, Alyeska and the tanker owners in upgrading the initial response capability to an oil spill in Prince William Sound. We still have some significant problems to work out in bringing the PWS compliance plans up to the response level required by HB 567 and I feel that the approach we are taking will continue to resolve these problems and will result in what we believe will be an oil spill prevention and response capability comparable to, or better than, any found throughout the world. We are still working on answers to questions regarding adequate oil industry oversight and the role of citizen groups is still being defined.

FORMATION OF PWS STEERING COMMITTEE AND INVOLVEMENT OF THE RCAC

The ADEC's initial reaction following the EXXON VALDEZ spill was to begin the process of upgrading Alyeska's and the oil shipping companies oil spill contingency plans by issuing an Emergency Order in April 1989. Among other items, the order required an increased amount of containment boom and skimming equipment and required that each outbound tanker be escorted from the terminal to Seal Rocks just past the Hinchinbrook Entrance.

The Emergency Order was followed by a Compliance Order by Consent, which established an increased response capability through an interim operating plan and required that Alyeska revise their existing contingency plan. This revised plan was submitted to the Department on December 31, 1989. The Department began a comprehensive review of the plan while at the same time the Alaska Legislature began to consider new spill response legislation. As the new legislation progressed and we delved more deeply into the contingency plan, it became apparent that a number of issues regarding the adequacy of the plan and transition for spill responsibility to the spiller were developing that would take major efforts to resolve. In fact, ADEC realized that some of the questions were beyond the capability of the Department to resolve without technical input from the industry, the Coast Guard and the public. In addition, we had to attempt to work with Alyeska to develop an approvable contingency plan while new, broad sweeping legislation (and the subsequent regulations) we were going to have to implement were just fresh off the press.

As a result of this, an informal working group approach was established to lay issues on the table for open consideration. The initial working group was comprised of ADEC, the USCG, and Alyeska. It soon became apparent that the then fledgling Prince William Sound Regional Citizens Advisory Council and the PWS tanker owners association were also needed to deal with the array of issues that surfaced.

These issues deal with:

- Shoreline response
- Transition Management from Alyeska to the spiller
- Prevention measures
- Oil recovery capacity
- Training/performance measures
- Waste disposal
- Cleanup strategy that provides for complimentary use of mechanical removal, dispersants, bioremediation and burning

It eventually became apparent that the Steering Committee needed operating protocols if it was going to survive. The Steering Committee Protocol that was finally agreed upon is included at the end of this paper.

NEW LEGISLATION

Alaska Oil and Hazardous Substance Pollution Control Statutes require tanker vessels in the Trans-Alaska Pipeline trade that have a capacity of 500,000 barrels or more to meet a contingency response planning standard. The standard requires the plan holder to maintain in its region of operation, in this case in Prince William Sound, equipment, personnel and other resources sufficient to contain, control and clean up a 300,000 barrel spill within 72 hours. I want to emphasize that this is not a clean up standard.

Prince William Sound plan holders must maintain any equipment, personnel and other resources either within or outside the region of operation necessary to contain or control and clean up a realistic maximum discharge within the shortest possible time and must demonstrate that these resources are accessible and will be deployed and operating at the discharge site within 72 hours.

Legislation was also passed establishing the State Spill Response Office to deal with spills of hazardous substances and catastrophic oil spills (100,000 barrels or greater). The financial responsibility for companies transporting and storing crude oil was increased. A State Emergency Response Commission was created to implement SARA Title III and to ensure that local, regional and statewide contingency plans [illegible] grated and coordinated with each other [illegible] facility and vessel plans. A Citizens' Ove[illegible] Council was formed to promote an involved citizenry as well as providing a forum for citizen participation. The Council has among its duties to serve as a watchdog of State and Federal agencies with responsibilities for the prevention of and response to oil and hazardous substances and to help develop interstate compacts regarding prevention of spills.

DRAFT REGULATIONS

The Steering Committee/Working Groups have put much time and effort into developing meaningful solutions and recommendations to the problems that had been identified within the context of the new legislation. The Department is considering utilizing the results of the Steering Committees working groups to establish response performance criteria based on demonstrated performance as a means of evaluating compliance with the new law. Also, one of the goals of the Steering Committee was to utilize the expertise that had been and was being brought together in the development of implementing regulations for the new law.

In addition to the requirements set out in the new statutes, the current draft regulations out for comment, would set the realistic maximum oil discharge for tanker vessels having a total cargo capacity of 500,000 barrels or greater at 60 percent of the total cargo capacity. These draft regulations would require the use of mechanical response methods of oil control, containment and clean up and must consist of the best available technology. Response equipment and vessels would be required to be of such design that they can operate effectively in 30 knot winds, 1.5 knot currents and 10 foot waves unless it can be demonstrated that conditions reaching that severity do not occur. The regulations would also give the Department the authority to require specific prevention measures including the temporary suspension of operations if necessary to eliminate or significantly reduce the risk or the magnitude of an oil discharge during periods when mechanical clean up are rendered ineffective due to environmental conditions.

The regulations would also require provisions for (1) appropriate means to track and immediately report movement of discharged oil (when greater than 500 barrels), (2) boom of proper types and sufficient lengths to contain 300,000 barrels or the RMOD amount of oil, (3) demonstration that the number and types of vessels to deploy and tow boom is adequate, (4) demonstration that there are enough response equipment, personnel and other resources available to exclude spilled oil from sensitive environmental areas and areas of public concern, (5) sufficient lightering equipment and personnel, (6) demonstration that the number, type and size of skimmers and pumps are adequate for recovery of the type and volume of oil spilled within the planning standard time frame, (7) the availability of adequate temporary storage and removal capacity for recovered oil and oily waste on site to keep up with the skimming and recovery operations, (8) demonstration of the onsite ability to separate water from recovered oily water mixture so that the recovered water discharged meets state water quality standards.

PLANNING STANDARDS

The Department and the Steering Committee have spent quite a bit of effort trying to come to terms with the definition of the nameplate skimming capacity needed to satisfy the requirements of the new legislation. Figure 1 shows the amount of oil estimated recovered for four different proposed 72 hour response planning standards assuming 300,000 barrels were released over a six hour period for 10% and 30% recovery rates. Figure 2 shows the rate of oil recovery and the total recovery under ideal conditions. A Technical Analysis of Expected Skimmer Performance made by the Department is also available. The Department is currently working through one of the PWS Contingency Plan Steering Committee working groups to identify the level of response capability to propose as satisfying the requirements of Alaska's planning standard. The main components that Alyeska is planning to include in its response capability will probably consist of four skimming platforms each with two Transrec skimmers, a new dynamically inclined plane skimmer, two Dosec Arm skimmers possibly fitted to a tug and Seaskimmers on the Emergency Response Vessels (ERV). This will give Alyeska a "nameplate" skimming capability of about 23,400 barrels/hour. In addition, Alyeska is working on a skimming head concept using lightering pumps that we anticipate will be effective during the early hours of a spill which could increase their skimming capacity by another 6,000 barrels/hour giving a maximum "nameplate plus pumping rate" capacity of 29,400 barrels/hour.

We realize that this is an idealistic recovery capacity and that even under perfect conditions they may achieve only a fraction of this capacity. However, we have to arrive at a base skimming capability and we are still working out the kinks to arrive at a limit we can agree on. Even more importantly, we must look at methods to reduce the risk of catastrophic spills or reduce the magnitude of oil released in the event of a spill. The RCAC is playing a major role in gathering data and information and in working towards the development of a tanker escort system in high risk areas of PWS to supplement the existing escort system. When we exceed the limits or operational capabilities of any protective measures, then operations must be restricted or shut down.

ADEC INVOLVEMENT WITH RCAC

The Department was given additional positions by the 1990 legislature for contingency plan review, compliance inspections, spill drills and structural engineering review. Almost all of these positions were filled by December 1990. We now have staff to work closely with industry, the Coast Guard and RCAC. We recognize that the Department must provide information and educate members of RCAC to insure they have a thorough understanding of the Department's policies, requirements and regulations. The RCAC has been broadening its horizons and involvement in the environmental programs that apply to the oil industry. The RCAC involvement has been and is valuable in helping to develop approvable Prince William Sound contingency plans. We expect to take approval/disapproval actions on the Alyeska Marine Terminal contingency plan and the PWS tanker owners contingency plans by June 1, 1991. The actions will probably be conditional since the results of studies, decisions on skimming capacity, response strategies development and actions to implement all the components for a comprehensive contingency plan are not in place to meet all the requirements of HB 567 by June 1, 1991. Much work remains to be completed and we will be relying on the RCAC to be a part of that process. Even considering that we're not through, we feel that we have covered a tremendous amount of ground since March 24, 1989.

CONCLUSION

Regardless of how thorough or how successful we complete our task to have an emergency response capability comparable with any in the world, we will never be able to control, contain or remove all the oil from a catastrophic spill. This leads us to the conclusion that we have to prevent spills in the first place or, as a distant second best, reduce the size of any spills that might occur. It is in this direction that we are working - to identify high risk practices or areas and develop a means to reduce the risk. In Prince William Sound, I think we have made significant strides to eliminate an EXXON VALDEZ, full power on, type of grounding. Our present effort is to develop the measures to control and stop a disabled tanker in the high risk areas in Prince William Sound i.e. the Valdez Narrows and Valdez Arm and at Hinchinbrook Entrance. These measures coupled with a well trained, adequately equipped, initial response capability should raise our level of confidence in our ability to provide for the safe transport of oil through Prince William Sound.

PRINC WILLIAM SOUND
STEERING COMMITTEE PROTOCOL

1. MUTUALLY AGREE ON AGENDA AND SCHEDULE.

2. MUTUALLY AGREE ON REPORT OF MEETING.

3. ALL MEETINGS SHOULD BE OPEN TO ALL PARTIES; ADEC, USCG, RCAC, ALYESKA AND THEIR CONTRACTORS.

4. MUTUAL CONSENT THAT ALL TECHNICAL REPORTS, SUPPORTING ADEC AND ALYESKA CONCLUSIONS OR RECOMMENDATIONS OR POSITIONS, BE SUBJECT TO WORKING GROUP REVIEW AND DISCUSSION BEFORE DECISIONS ARE MADE.

5. ALL PARTIES RECOGNIZE THE WORLD SIGNIFICANCE OF OUR TASK AND THE ENORMOUS DIFFICULTY.

6. ALL PARTIES RECOGNIZE THE PRECARIOUS BALANCE OF FREEDOM THAT CURRENTLY EXISTS AUTHORIZING THIS WORKING GROUP PROCESS.

7. ALYESKA ACKNOWLEDGES THAT THE "WORKING GROUP" PROCESS CAN ONLY INFLUENCE THOSE DECISIONS SO LONG AS SOUND, TECHNICAL AND DEFENSIBLE PROPOSALS ARE BROUGHT TO BEAR ON A PARTICULAR PROBLEM.

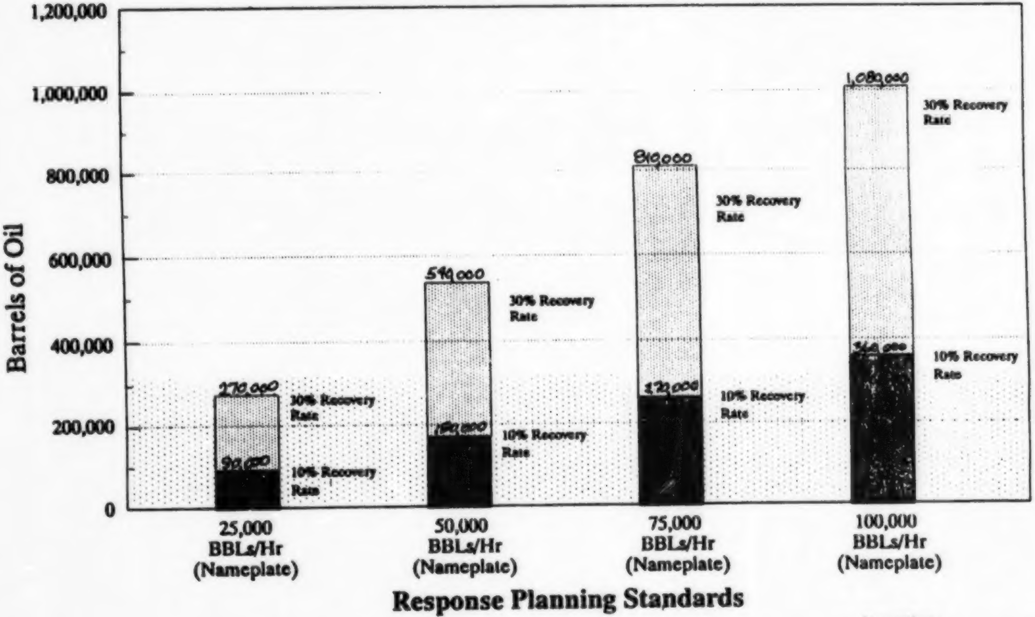
8. ALYESKA FREELY ACKNOWLEDGES ADEC RIGHTS AND AUTHORITY TO MAKE THE FINAL DECISIONS, SUBJECT TO NORMAL DUE PROCESS CRITERIA.

9. MUTUALLY AGREE THE TECHNICAL EQUIPMENT, STRATEGY AND PREVENTION ISSUES RESULTING FROM THESE MEETINGS BE FORWARDED TO PERSONS DEVELOPING REGULATIONS FOR HB 567.

10. MUTUALLY AGREE THE OUTSTANDING ISSUES OF DISPERSANTS, OILY WASTE DISPOSAL AND THE RELATIONSHIPS BETWEEN THE PWS PLAN AND THE TANKER OWNERS PLAN ARE SUBJECT TO ABOVE 1 THROUGH 8.

Proposed 72 Hour Response Planning Standards For Crude Tank Vessels

Amount of Oil Recovered in 72 Hours



Highest ever open water recovery < 10%.
Total estimated recovery from EXXON/Valdez 6%.
Recovery from EXXON/Valdez in 72 hours < 2%.

Assumptions:

- Spill occurs on Bligh Reef and releases 300,000 Barrels during the first six hours (50,000 barrels/hour).
- Daylight operations i.e. 36 Hours

Prince William Sound
Spill Recovery Capability